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Philip R. Laun, et al

Texas Instruments, Incorporated

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This report describes the results of the continued evaluation of the Norwegian Long-Period Seismic Array (NORSAR) by Texas Instruments Incorporated at the Seismic Data Analysis Center during the period 1 April 1972 to 31 March 1973. The NORSAR Evaluation was concerned with five major areas of study:

- Noise analysis

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20. continued

- Array processing performance
- Effectiveness of matched filters
- Surface wave detection capability
- Performance of standard surface wave discriminants.

This evaluation used 324 Eurasian events and 32 noise samples taken the period of 1 January 1972 to 26 December 1972. These data were combined with earlier NORSAR data, when applicable, so as to maximize the data base.

CONTINUED EVALUATION OF THE NORWEGIAN LONG-PERIOD ARRAY

SPECIAL REPORT NO. 7

EXTENDED ARRAY EVALUATION PROGRAM

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ABSTRACT

This report describes the results of the continued evaluation of the Norwegian Long-Period Seismic Array (NORSAR) by Texas Instruments Incorporated at the Seismic Data Analysis Center during the period 1 April 1972 to 31 March 1973 The NORSAR evaluation was concerned with five major areas of study:

- Noise analysis
- Array processing performance
- Effectiveness of matched filters
- Surface wave detection capability
- Performance of standard surface wave discriminants

This evaluation used 324 Eurasian events and 32 noise samples taken from the period of 1 January 1972 to 26 December 1972. These data were combined with earlier NORSAR data, when applicable, so as to maximize the data base.

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SECTION I

INTRODUCTION

This report presents results of the evaluation of the Norwegian Long-Period Seismic Array (NORSAR) made during the period from April 1972 through March 1973. This work is a continuation of an analysis of NORSAR reported on earlier (Eyres, Laun, and Swindell, 1972). The evaluation was directed toward two major goals: the determination of the detection and discrimination capabilities of NORSAR and the investigation of methods which sustain or enhance those capabilities. Five separate studies were made:

- Noise analysis
- Array processing effectiveness
- Matched filter performances
- Signal detection threshold estimation
- Behavior of standard discriminants

The results from these studies are discussed in Sections III through VII. When possible, results from the first report have been included with those obtained this year so as to maximize the data base. The total data base is described in Section II. Section VIII summarizes the results and conclusions and suggests areas of future NORSAR long-period analysis.

SECTION II
DATA BASE

The results presented in this report are based mainly on seismic events recorded during two periods in 1972: 1 January through 20 March, and 1 June through 31 July. Other events from 1972 include all reported presumed explosions from the Sino-Soviet area. There were 324 events successfully processed from 1972. Finally, 59 events from 1971, which were reported on last year, have been included.

Table II-1 lists these 383 events and various parameters associated with them, including: name (the three-part designator consists of region, julian date, and hour of origin time. A "/" indicates a 1971 event; an "*" indicates a 1972 event), date and origin time, epicenter location, delta and azimuth from NORSAR, bodywave magnitude (m_b), surface wave magnitudes for vertical (Rayleigh) and transverse (Love) components, converted AR and AL values, depth (if reported), and coded comments. The comments include a letter indicating the source of event information, an "X" if the event is a presumed explosion, and the number of sites used to form the array beam. The source codes are "P" for the National Oceanic and Atmospheric Administration (NOAA) Preliminary Determination of Epicenters (PDE) bulletin, "L" for the Montana Large Aperture Seismic Array (LASA) bulletin, "N" for the NORSAR bulletin, and either an "I" or a "J" for the Massachusetts Institute of Technology-Lincoln Lab bulletin for the International Seismological Month (ISM), which was from 20 February to 19 March 1972.

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TABLE II-1

LIST OF EVENTS USED FOR EVALUATION

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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AF	AL	Z	NOTES
TIR/122/00	05/02	00.33.22	30.8/ 94.5	55.6/ 87.4	5.4	5.2	-	147	144	16	P (11)
TUP/126/04	05/06	04.24.34	39.0/ 29.7	24.8/142.3	4.6	4.4	-	-	-	N	P (13)
CAS/135/04	05/15	04.53.05	38.1/ 49.1	32.9/116.2	4.6	3.3	-	33	40	N	P (9)
KUR/135/21	05/15	21.03.46	43.4/147.3	69.9/ 32.2	4.7	4.1	-	72	41	48	P (9)
TUR/143/01	05/23	01.02.55	37.4/ 30.1	24.2/143.8	4.4	4.0	-	-	-	N	P (16)
EKZ/145/04	05/25	04.03.58	49.8/ 78.2	38.0/ 75.4	5.2	3.6	-	1.8	-	0	PX(16)
KUR/146/01	05/26	01.46.11	43.5/146.7	69.7/ 32.6	4.7	4.0	-	40	23	59	P (15)
TRZ/147/00	05/27	00.30.29	39.3/ 69.0	42.0/ 95.2	4.8	4.1	-	68	41	36	P (16)
KUR/147/16	05/27	16.50.31	43.8/146.4	69.3/ 32.7	5.2	4.4	-	22	25	36	P (11)
KOM/148/10	05/28	10.21.43	55.9/166.6	61.8/ 15.2	4.5	4.1	-	201	104	N	P (14)
KUR/152/21	06/01	21.20.27	43.6/150.2	70.4/ 30.1	4.6	3.5	-	26	11	N	P (11)
TIR/155/20	06/04	20.49.58	32.2/ 92.1	58.1/ 80.0	5.0	4.1	-	13	30	N	P (13)
CHI/156/10	06/05	10.21.28	37.3/113.7	63.7/ 59.9	4.7	5.0	-	186	316	N	P (15)
EKZ/157/04	06/06	04.02.57	50.0/ 77.8	37.6/ 75.5	5.5	3.5	-	2.0	1.8	0	PX(13)
TUR/161/09	06/10	09.31.54	39.1/ 29.6	24.7/143.3	4.9	4.3	-	-	-	N	P (16)
FRS/165/13	06/14	13.49.56	56.2/123.6	51.6/ 40.9	5.6	5.6	-	201	239	N	P (11)
FRS/165/14	06/14	14.25.57	56.2/123.5	51.6/ 41.0	4.6	-	-	-	-	N	P (16)
KAM/166/14	06/15	14.04.08	52.9/160.8	63.8/ 19.7	5.1	4.7	-	69	72	55	P (11)
SIN/166/22	06/15	22.04.13	41.5/ 79.3	44.5/ 93.2	5.6	4.8	-	254	463	N	P (15)
SIN/166/23	06/15	23.17.34	41.6/ 79.3	44.4/ 93.2	4.9	4.1	-	22	28	N	P (17)
EKZ/170/04	06/19	04.03.58	50.0/ 77.7	37.6/ 75.6	5.5	3.3	-	1.1	1.2	0	PX(15)
SIN/170/17	06/19	17.23.03	41.5/ 79.3	44.5/ 33.3	5.2	5.3	-	205	207	N	P (15)
KUR/190/16	07/09	16.44.16	43.5/147.7	69.9/ 31.9	4.9	4.9	-	217	224	46	P (19)
KUR/191/03	07/10	03.05.00	43.6/147.7	69.8/ 31.9	4.9	4.4	-	97	74	36	P (16)
KUR/191/09	07/10	09.01.35	45.0/150.5	69.2/ 29.3	4.6	3.4	-	-	-	N	P (17)

TABLE II-1

LIST OF EVENTS USED FOR EVALUATION
PAGE 2 OF 16

EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
WRS/191/17	07/10	16.55.59	64.3/ 55.2	30.3/ 61.3	5.3	-	-	-	-	0	RX(13)
SPS/200/20	07/19	20.41.20	49.1/ 39.6	19.5/114.4	3.3	3.1	-	-	-	N	L (19)
CHI/208/13	07/27	12.48.32	39.0/ 73.0	45.8/ 96.6	5.3	4.6	-	-	-	N	L (14)
BSA/210/19	07/29	19.40.15	42.6/ 33.2	22.7/123.6	4.5	2.6	-	-	-	N	L (16)
SIB/213/01	07/31	01.11.20	61.5/163.2	55.9/ 15.5	3.5	3.4	-	-	-	N	L (17)
KUR/213/02	08/01	02.06.07	50.4/156.9	65.4/ 23.1	5.6	5.4	-	-	-	20	P (19)
SIN/219/15	08/07	15.21.53	36.1/ 77.7	48.0/ 99.3	4.8	4.3	-	125	263	N	P (15)
SIN/221/01	08/09	01.03.17	42.1/ 83.4	46.0/ 79.4	4.2	3.4	-	49	58	N	P (13)
CHI/229/09	08/17	09.36.16	28.9/103.7	66.4/ 72.7	4.9	4.5	-	59	75	N	P (11)
CHI/229/17	08/17	17.07.40	28.9/103.7	66.4/ 72.7	4.9	4.0	-	30	31	N	P (7)
CRS/236/16	08/24	16.32.23	52.2/ 91.4	42.3/ 63.9	5.2	5.7	-	904	324	N	P (15)
SIN/241/15	08/29	15.16.57	36.5/ 78.5	48.0/ 88.3	5.0	-	-	-	-	N	P (9)
CHI/249/21	09/06	21.46.46	43.9/122.6	62.1/ 48.9	3.8	3.5	-	77	128	N	P (15)
TRS/251/22	09/08	22.35.16	41.1/ 43.8	28.1/119.6	4.8	4.4	-	260	398	N	P (15)
CHI/258/07	09/15	07.10.47	33.0/101.0	61.7/ 72.4	4.2	3.10	-	-	-	N	N (13)
CHI/258/11	09/15	11.22.43	24.0/101.0	60.9/ 71.7	4.2	-	-	-	-	N	N (14)
TDZ/259/10	09/16	10.59.27	40.0/ 68.0	40.7/ 94.5	4.2	-	-	-	-	N	N (9)
CAU/262/06	09/19	06.44.49	43.0/ 47.1	29.0/113.0	4.4	-	-	-	-	N	L (11)
BLS/263/06	09/20	06.16.58	44.0/ 33.0	21.4/132.0	4.0	3.7	-	936	656	N	L (14)
BLS/263/08	09/20	08.02.51	43.2/ 32.9	22.0/133.2	4.2	-	-	-	-	N	L (14)
BLS/263/10	09/20	10.57.49	43.3/ 32.3	21.7/134.1	4.2	3.5	-	163	173	N	L (10)
FRS/266/21	09/23	21.08.03	53.4/120.3	52.8/ 44.9	4.2	3.2	-	-	-	15	L (13)
SIN/273/12	09/30	12.43.45	50.0/ 78.0	42.4/ 69.4	4.5	4.2	-	79	65	N	N (15)
TDZ/274/16	10/01	16.27.48	38.6/ 69.8	42.1/ 94.1	4.9	4.3	-	67	36	36	P (15)
FKZ/282/06	10/09	06.02.57	50.0/ 77.7	37.6/ 75.6	5.4	2.8	-	2.5	2.0	0	RX(13)

TABLE II-1

LIST OF EVENTS USED FOR EVALUATION

EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
CAU/283/09	10/10	09.06.06	43.1/ 43.8	26.4/117.0	4.0	3.3	–	114	191	15	L (12)
CAU/288/17	10/15	17.08.06	41.4/ 48.6	29.9/113.1	4.9	3.6	–	45	42	N	P (15)
EKZ/294/06	10/21	06.02.57	50.0/ 77.6	37.6/ 75.6	5.6	3.1	–	2.7	2.2	0	PX(10)
KRG/301/13	10/28	13.30.57	41.9/ 72.4	40.9/ 88.7	5.5	5.2	–	227	298	N	P (15)
TIB/302/17	10/29	17.16.52	34.0/ 86.0	53.7/ 83.8	5.0	4.7	–	50	75	N	N (13)
EKZ/333/06	11/29	06.02.57	49.8/ 78.1	37.9/ 75.5	5.5	3.4	–	2.9	2.9	0	PX(5)
EKZ/349/07	12/15	07.52.59	50.0/ 77.9	37.7/ 75.4	4.9	–	–	–	–	0	PX(17)
WKZ/356/06	12/22	06.59.56	47.9/ 48.2	24.8/104.4	6.0	4.5	–	12	3.2	0	PX(17)
EKZ/364/06	12/30	06.20.58	49.7/ 78.1	38.0/ 75.6	5.8	3.9	–	3.9	2.2	0	PX(13)
SIB*001*15NL	01/01	15.04.19	59.7/153.8	56.1/ 21.5	4.1	–	–	–	–	N	L (12)
KUR*001*16NL	01/01	16.55.06	50.7/155.8	65.0/ 23.7	4.6	–	3.6	30	44	N	L (16)
KUR*001*18NL	01/01	18.13.54	49.4/156.5	66.3/ 23.7	4.0	3.6	–	–	–	N	L (14)
KUR*002*05NB	01/02	05.37.25	46.1/146.2	67.1/ 32.0	4.0	–	–	–	–	N	L (17)
GRF*002*09NA	01/02	09.17.53	37.9/ 20.7	23.8/160.5	4.2	2.5	2.6	40	46	N	P (14)
SIN*002*10NA	01/02	10.27.35	41.8/ 84.5	46.8/ 78.8	5.2	4.2	4.2	29	30	N	P (19)
KAM*003*06NL	01/03	06.36.38	51.6/159.4	64.8/ 21.0	4.8	3.9	3.9	56	55	N	P (13)
KAM*003*19NL	01/03	19.26.43	52.0/159.0	64.3/ 21.2	4.5	–	3.5	–	47	N	N (16)
ERS*003*23NL	01/03	23.40.37	58.8/130.8	51.6/ 35.0	3.4	–	–	–	–	N	L (15)
KAM*004*02NL	01/04	02.29.18	55.6/161.2	61.2/ 18.6	4.3	3.5C	3.6	–	128	N	L (15)
TAI*004*05NC	01/04	05.08.48	22.4/122.0	80.2/ 61.1	4.8	3.9	4.1	365	461	N	P (17)
KAM*004*10NL	01/04	10.42.31	55.6/163.8	61.6/ 17.0	4.4	–	–	–	–	N	L (14)
TAI*004*12NA	01/04	12.15.17	22.4/122.2	80.3/ 60.9	4.6*	4.9	5.1	360	547	N	P (16)
KUR*005*02NL	01/05	02.16.10	43.8/147.2	69.5/ 32.2	4.5	3.4	3.2	32	29	N	P (12)
AUS*005*04NA	01/05	04.57.41	47.8/ 16.2	13.4/164.4	4.0	2.6	2.8	112	109	N	P (12)
TDZ*005*12NA	01/05	12.02.54	37.8/ 73.1	44.4/ 91.9	4.5	3.0	2.9	22	23	N	L (14)

TABLE II-1

LIST OF EVENTS USED FOR EVALUATION
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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
KOM*005*14NL	01/05	14.26.48	56.6/169.4	61.3/ 13.3	4.0	-	-	-	-	N	L (14)
KAM*005*16NL	01/05	16.09.50	57.3/160.5	59.5/ 18.5	3.9	3.20	3.30	-	-	N	L (12)
KRG*006*06NC	01/06	06.30.36	40.7/ 72.4	41.8/ 89.8	4.7	3.4	3.0	23	13	N	P (13)
TAI*006*06NL	01/06	06.33.34	23.3/123.4	80.0/ 59.5	4.7	4.0	4.2	36	36	N	P (12)
IRA*006*09NL	01/06	09.41.33	30.3/ 50.5	40.1/121.3	5.2	3.6	3.6	15	16	N	P (14)
SWR*007*20NL	01/07	20.37.32	44.1/ 45.1	26.2/114.0	4.2	-	-	-	-	N	L (6)
KOM*009*03NL	01/09	03.23.06	54.4/164.4	62.9/ 17.0	3.6	-	-	-	-	N	L (17)
KAM*009*14NL	01/09	14.00.59	55.7/163.6	61.5/ 17.1	4.3	-	3.90	-	-	N	P (14)
KUR*009*14NL	01/09	14.47.46	45.1/148.4	68.6/ 30.8	3.8	-	-	-	-	N	L (15)
TAI*010*05NL	01/10	05.23.52	20.9/120.4	80.8/ 63.1	5.0	4.3	4.7	49	82	N	P (16)
KOM*011*03NL	01/11	08.54.34	54.7/168.2	63.1/ 14.5	3.9	-	-	-	-	N	L (15)
GRE*012*13NL	01/12	13.51.20	35.0/ 23.5	27.1/156.9	4.9	4.2	3.9	267	153	N	P (18)
KAM*012*20NL	01/12	20.20.15	55.6/163.9	61.6/ 16.9	4.8	4.2	4.3	111	127	N	P (17)
SIB*013*17NL	01/13	17.24.07	61.9/147.1	52.8/ 24.2	5.3	5.2	5.0	442	219	N	P (19)
SIB*014*03NA	01/14	03.20.20	67.5/171.5	50.9/ 6.4	3.9	3.2	3.1	187	186	N	P (15)
IRA*014*22NL	01/14	22.10.04	32.8/ 46.9	36.5/123.7	5.1	3.7	4.0	40	51	N	P (17)
KUR*015*00NA	01/15	00.58.33	49.6/155.0	65.9/ 24.6	3.9	-	-	-	-	N	L (20)
FRS*015*18NL	01/15	18.07.59	57.4/120.7	49.7/ 41.6	4.7	3.6	3.9	37	66	N	P (16)
KAM*016*04NL	01/16	04.38.16	55.6/162.5	61.4/ 17.8	3.8	-	-	-	-	N	L (17)
KAM*016*11NL	01/16	11.00.49	55.6/163.2	61.5/ 17.4	3.9	-	-	-	-	N	L (14)
CRE*017*05NL	01/17	05.54.20	34.5/ 26.5	28.2/152.0	4.1	2.8	2.9	72	72	N	L (16)
IRA*018*21NL	01/18	21.12.02	37.5/ 49.7	33.2/117.3	4.9	3.4	3.9	48	86	N	P (16)
DOD*020*02NL	01/20	02.15.07	36.6/ 27.1	26.3/149.6	4.8	4.0	3.7	171	103	N	P (18)
CAU*021*23NL	01/21	23.30.46	43.2/ 45.3	27.0/115.0	3.9	-	-	-	-	N	L (18)
KUR*022*01NL	01/22	01.41.24	50.0/152.0	64.8/ 26.5	4.2	3.00	-	-	-	N	N (16)

TABLE II-1

LIST OF EVENTS USED FOR EVALUATION
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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
TUR*022*17NL	01/22	17.17.31	37.6/ 29.2	26.1/144.1	4.4	2.7	2.6	-	-	N	P (16)
KAM*025*10NL	01/25	10.02.40	53.9/160.9	42.9/ 19.3	4.6	-	-	-	-	N	P (16)
CRE*026*12NL	01/26	12.54.39	34.5/ 25.5	23.0/153.7	4.0	-	-	66	-	N	L (14)
KAM*027*20NL	01/27	20.37.24	55.7/162.2	61.2/ 17.9	3.8	-	-	-	-	N	L (14)
CHI*028*04NL	01/28	04.22.28	27.5/126.5	77.5/ 55.0	4.4	4.0	4.0	86	90	N	L (15)
IWP*028*10NL	01/28	10.24.54	26.6/ 66.3	50.3/107.0	5.0	3.9	3.9	4.3	4.1	N	P (13)
KRG*028*20NL	01/28	20.29.19	43.0/ 78.0	42.8/ 82.9	4.4	2.9	3.4	23	39	N	N (17)
FRS*029*21NL	01/28	21.50.00	45.0/136.0	65.2/ 39.6	4.0	-	-	-	-	N	N (15)
KUR*029*23NL	01/28	23.42.51	49.3/157.3	66.6/ 23.1	3.8	-	2.20	-	-	N	L (18)
IRA*029*09NL	01/29	09.50.58	29.0/ 62.0	46.3/109.7	3.9	3.1	2.9	90	104	N	N (19)
CHI*030*03NL	01/30	03.56.41	40.9/120.2	63.3/ 53.0	3.9	4.2	4.2	350	338	N	L (17)
KAM*032*10NL	02/01	10.16.09	55.8/162.8	61.3/ 17.6	4.1	-	-	-	-	N	L (14)
SIB*032*17NL	02/01	17.06.25	59.3/155.7	56.8/ 20.6	3.6	-	-	-	-	N	L (12)
KAM*033*04NL	02/02	04.26.59	55.7/162.0	61.2/ 19.1	3.7	-	-	-	-	N	L (18)
KUR*033*09NL	02/02	09.58.51	46.8/146.4	66.5/ 31.5	3.6	-	-	-	-	N	L (14)
KUR*033*17NL	02/02	17.56.39	50.7/160.1	65.8/ 20.8	3.6	-	-	-	-	N	L (18)
GRF*033*21NL	02/02	21.19.49	38.9/ 21.2	22.9/159.0	4.6	3.3	3.6	103	154	N	P (19)
CHI*034*07NL	02/03	07.22.49	23.4/102.4	70.4/ 76.8	4.5	4.1	4.5	118	200	N	P (17)
ITA*035*02NL	02/04	02.42.19	42.8/ 13.3	17.1/174.1	4.5*	3.7	4.3	300	925	N	P (15)
BKL*035*03NL	02/04	03.24.56	51.4/119.0	53.6/ 47.8	4.2	3.4	3.1	58	45	N	L (15)
ITA*035*04NL	02/04	04.40.55	43.9/ 13.2	17.0/174.3	4.9	-	2.10	-	-	N	P (17)
ITA*035*09NL	02/04	09.18.32	43.9/ 13.2	17.0/174.3	4.4	3.4	3.9	159	466	N	P (14)
ITA*035*17NL	02/04	17.19.52	43.8/ 13.3	17.1/174.1	4.1*	3.3	3.8	401	834	N	P (17)
ITA*035*19NL	02/04	19.02.56	43.8/ 13.3	17.1/174.1	4.1*	2.6	3.2	90	198	N	P (15)
ITA*036*03NL	02/05	03.49.45	43.2/ 13.7	17.7/173.2	3.7*	2.3	2.8	107	280	N	P (19)

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LIST OF EVENTS USED FOR EVALUATION
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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
ITA*036*05NL	02/05	05.05.51	43.7/ 13.5	17.2/173.6	4.0*	2.8	3.3	175	345	N	P (19)
ITA*036*07NL	02/05	07.08.13	43.9/ 13.3	17.0/174.0	4.3*	3.2	3.6	137	275	N	P (18)
ITA*036*15NL	02/05	15.14.48	43.7/ 13.4	17.2/173.8	4.2*	3.4	3.9	379	757	N	P (18)
ITA*037*01NL	02/06	01.34.22	44.0/ 13.2	16.9/174.3	4.4*	3.1	3.7	101	273	N	P (19)
TIB*037*04NL	02/06	04.29.05	29.0/ 89.0	59.3/ 84.7	4.1	-	-	-	-	N	N (19)
ITA*037*21NL	02/06	21.44.29	43.8/ 13.2	17.1/174.3	3.8*	-	2.6	109	116	N	P (20)
ITA*039*12NL	02/08	12.19.15	43.8/ 13.3	17.1/174.1	4.3*	2.5	2.9	35	71	N	P (16)
EKZ*041*05NL	02/10	05.02.57	50.0/ 78.9	38.2/ 74.7	5.5	2.7	-	1.2	-	O	PX(19)
IRA*041*09NL	02/10	09.04.09	29.6/ 50.9	40.9/121.4	3.9	3.1	3.4	153	252	N	P (19)
IRA*041*16NL	02/10	16.40.16	29.5/ 50.9	41.0/121.4	4.1	3.2	3.4	120	199	N	P (19)
SIN*042*05NL	02/11	05.55.46	39.9/ 77.4	44.8/ 86.3	4.9	4.2	4.3	56	67	N	P (18)
TIB*042*12NA	02/11	12.20.43	29.0/ 87.0	58.3/ 86.4	4.3	-	-	-	-	N	N (16)
KAM*042*21NA	02/11	21.36.17	56.1/162.9	61.0/ 17.4	4.6	3.9	4.2	124	156	N	P (18)
KUR*044*05NA	02/13	05.24.57	43.5/147.0	69.7/ 32.4	3.8	-	-	-	-	N	L (21)
GRE*044*13NL	02/13	13.07.11	37.1/ 24.0	25.1/154.8	4.5	3.2	3.8	89	192	N	P (21)
KOM*044*22NA	02/13	22.36.54	55.2/165.5	62.2/ 16.1	3.9	3.8C	3.8C	-	-	N	L (21)
KUR*046*16NL	02/15	16.45.22	45.0/153.0	69.8/ 27.6	4.1	3.0	2.7C	42	-	N	L (18)
GRE*047*00NL	02/16	00.42.24	36.9/ 24.2	25.4/154.6	4.5	2.9	3.4	39	89	N	P (20)
SIN*047*23NF	02/16	23.19.20	41.7/ 80.7	45.1/ 82.0	4.8	4.0	3.5	41	22	N	P (16)
KUR*049*18NA	02/18	18.02.34	43.6/147.8	69.8/ 31.8	4.7	3.8	3.8	39	52	N	P (18)
SIN*051*10NL	02/20	10.22.46	38.5/ 90.5	52.2/ 76.8	3.9	3.2	2.9	67	53	N	I (19)
KAM*051*20NL	02/20	20.06.11	50.8/141.5	61.6/ 33.1	4.1	3.2	-	61	-	N	I (19)
KAM*052*22NL	02/21	22.00.59	54.4/161.3	62.4/ 18.9	4.8	3.7	-	56	-	N	I (21)
YUG*052*23NA	02/21	23.02.55	41.0/ 23.3	21.0/155.4	4.0	-	-	-	-	N	I (18)
MON*053*01NC	02/22	01.53.36	49.0/115.0	54.5/ 51.4	4.1	-	-	-	-	N	I (14)

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LIST OF EVENTS USED FOR EVALUATION
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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
KAM*053*03NC	02/22	03.38.29	56.0/156.0	60.0/ 21.7	3.4	-	-	-	-	N	J (17)
HNK*053*08NA	02/22	08.14.26	36.6/ 68.6	43.1/ 97.1	4.0	3.2	3.1	112	68	N	J (17)
KUR*054*03NA	02/23	03.07.04	43.7/148.4	69.9/ 31.3	4.8	4.0	4.3	62	87	N	I (19)
KUR*054*27NB	02/23	03.21.31	44.2/148.4	69.4/ 31.1	4.7	3.9	4.2	54	90	N	I (18)
KUR*054*37NB	02/23	03.42.41	43.9/148.3	69.7/ 31.3	4.9	4.0	4.2	40	56	N	I (19)
ARC*054*09NL	02/23	09.46.50	86.0/139.0	31.8/ 6.0	3.7	-	-	-	-	N	J (17)
KAM*054*19NL	02/23	19.37.29	55.0/163.0	62.1/ 17.7	3.7	-	-	-	-	N	J (19)
KUR*055*10NA	02/24	10.19.37	48.8/155.7	66.7/ 24.4	5.0	4.9	4.5	297	132	N	P (13)
KUR*055*18NL	02/24	18.17.34	49.0/158.0	67.0/ 22.8	3.5	-	-	-	-	N	J (19)
KUR*056*19NA	02/25	19.59.29	46.0/147.0	67.4/ 31.4	3.9	-	-	-	-	N	J (16)
WRS*056*22NC	02/25	22.34.49	50.0/ 38.0	18.6/113.3	3.7	-	-	-	-	N	J (19)
KUR*056*22NL	02/25	22.43.07	49.2/156.0	66.4/ 24.1	4.0	3.3	3.1	102	-	N	I (19)
KUR*057*02NL	02/26	02.12.57	49.2/156.2	66.5/ 23.9	4.9	4.8	4.5	207	153	N	I (18)
KUR*057*05NL	02/26	05.58.22	46.8/152.6	68.0/ 27.2	4.9	3.5	3.5	23	16	N	I (19)
KAM*057*09NL	02/26	09.04.32	55.0/162.0	61.9/ 18.3	3.3	-	-	-	-	N	J (20)
SIB*057*15NL	02/26	15.06.42	53.3/138.7	58.6/ 33.6	3.8	-	-	-	-	N	I (18)
OKH*057*18NA	02/26	18.32.26	51.0/149.0	63.2/ 28.1	4.0	-	-	-	-	N	J (17)
YUN*057*18NL	02/26	18.56.13	27.1/100.9	66.6/ 76.0	4.7	3.9	4.0	36	39	N	P (17)
NRS*058*08NL	02/27	08.42.59	88.0/ -74.	29.0/ -4.1	3.3	-	-	-	-	N	I (10)
NRS*058*32NL	02/27	08.48.08	89.0/ 15.0	28.2/ 0.1	3.3	-	-	-	-	N	J (10)
NRS*058*10NL	02/27	10.03.03	87.0/ 53.5	27.0/ 4.5	4.9	3.9	3.6	151	126	N	I (19)
NRS*058*11NL	02/27	11.03.19	90.0/ -95.	29.2/ 0.0	3.5	-	-	-	-	N	I (19)
NRS*058*17NL	02/27	17.50.25	86.2/ 77.2	27.8/ 7.5	4.4	2.9	2.7	40	47	N	I (18)
BAI*058*22NL	02/27	22.15.03	55.0/ 93.2	41.2/ 59.7	4.5	3.1	3.0	25	23	N	I (20)
KUR*059*01NL	02/28	01.04.22	46.0/148.0	67.7/ 30.7	4.2	-	-	-	-	N	I (20)

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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
PAK*059*05NL	02/28	05.18.56	36.7/ 71.4	44.4/ 94.4	4.2	2.8C	-	-	-	N	I (19)
KAM*059*11NL	02/28	11.35.31	56.0/163.0	61.1/ 17.4	4.1	-	-	-	-	N	I (19)
AFG*059*18NL	02/28	18.12.35	36.0/ 68.7	43.7/ 97.5	4.4	3.9	3.4	151	64	N	I (12)
KAM*059*20NL	02/28	20.04.00	56.1/164.2	61.2/ 16.6	3.6	-	-	-	-	N	I (17)
IRQ*060*08NL	02/29	08.02.51	32.8/ 46.6	36.3/124.1	4.0	2.7C	3.2	-	110	N	I (19)
NPS*060*08NL	02/29	08.07.21	89.0/ -51.	28.7/ -1.8	3.4	-	-	-	-	N	J (18)
IRA*062*14NL	03/02	14.10.13	31.6/ 42.1	35.7/130.8	4.0	-	-	-	-	N	I (13)
ALM*062*19NL	03/02	19.57.42	43.0/ 76.0	41.8/ 84.5	3.5	-	-	-	-	N	J (20)
KAM*063*00NL	03/03	00.39.23	53.0/159.2	63.4/ 20.7	4.1	-	-	-	-	N	I (16)
SIB*063*05NL	03/03	05.26.53	77.8/116.7	34.4/ 21.1	3.8	-	-	-	-	N	I (21)
KOM*063*08NL	03/03	08.13.55	55.8/163.9	61.4/ 16.9	4.1	-	-	-	-	N	I (18)
YUG*063*21NL	03/03	21.26.51	44.7/ 18.4	16.7/161.2	4.4*	3.4	3.7	-	-	N	I (20)
KUR*063*23NL	03/03	23.10.41	50.2/155.7	65.4/ 23.9	4.5	3.8	3.5	87	48	N	I (20)
SIN*064*04NL	03/04	04.00.09	40.2/ 79.0	45.4/ 84.7	4.5	3.9	3.6	87	53	N	I (20)
KAM*066*06NL	03/06	06.05.08	53.5/160.9	63.2/ 19.5	3.9	-	-	-	-	N	I (20)
KUR*066*09NL	03/06	09.59.09	45.0/150.0	69.1/ 29.7	3.7	-	-	-		N	J (19)
OKH*066*19NL	03/06	19.13.25	56.0/140.0	56.5/ 31.4	4.2	-	-	-	-	N	J (20)
CHI*066*23NL	03/06	23.17.53	40.0/103.0	56.8/ 66.2	4.5	-	-	-	-	N	J (20)
YUG*067*05NL	03/07	05.21.21	43.0/ 21.0	18.9/156.6	2.7	-	-	-	-	N	I (20)
OKH*068*02NL	03/08	02.38.11	51.2/151.9	63.7/ 26.1	4.2	-	-	-	-	N	I (19)
IRA*068*21NL	03/08	21.49.11	27.6/ 56.7	45.1/116.3	4.6*	3.7	3.5	66	43	N	I (19)
BUL*068*22NL	03/08	22.04.02	40.8/ 22.8	21.3/154.6	3.5	2.9	3.0	653	578	N	I (19)
FKZ*070*04NL	03/10	04.56.57	49.8/ 78.2	38.0/ 75.4	5.5	3.3	3.3	2.4	1.8	O	IX(17)
KUR*070*06NL	03/10	06.50.18	45.1/149.5	68.9/ 30.0	3.7	2.8C	3.1C	-	-	N	I (19)
ARC*071*06NL	03/11	06.4 .07	82. /143.3	35.0/ 10.3	3.6	-	-	-	-	N	I (21)

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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
KAS*071*13NL	03/11	13.31.39	35.0/ 76.0	48.0/ 91.7	4.1	-	-	-	-	N	J (20)
KUR*073*02NL	03/13	02.11.05	49.0/158.0	67.0/ 22.8	3.8	-	-	-	-	N	I (20)
AFG*073*05NL	03/13	05.49.13	37.0/ 70.0	43.5/ 95.4	4.0	-	-	-	-	N	I (20)
TIB*073*18NC	03/13	18.27.07	34.0/ 83.0	52.2/ 86.4	4.1	-	-	-	-	N	J (17)
IDA*074*02NT	03/14	02.43.37	44.0/-116.	66.7/-38.8	3.7	-	-	-	-	N	J (18)
TIB*075*06NL	03/15	06.00.33	30.4/ 84.5	55.9/ 87.6	5.3	3.9	3.9	17	19	N	I (20)
ARZ*077*00NL	03/17	00.29.01	32.3/-116.	77.2/-44.2	4.1	-	-	-	-	N	I (17)
KUR*077*07NL	03/17	07.49.02	49.0/156.2	66.7/ 24.0	5.2	3.5	3.1	61	44	N	I (19)
TAD*077*09NL	03/17	09.17.11	40.1/ 69.7	40.9/ 92.8	5.2	4.8	4.5	166	149	N	I (18)
IRA*077*17NL	03/17	17.11.28	28.0/ 54.0	43.6/119.0	3.9	-	-	-	-	N	J (19)
KAS*077*23NL	03/17	23.33.37	32.0/ 75.0	50.0/ 94.9	3.5	-	-	-	-	N	J (18)
EKZ*078*07NL	03/18	07.11.55	47.0/ 81.0	41.3/ 76.5	3.6	2.9	-	114	-	N	J (20)
KAM*078*13NL	03/18	13.52.14	57.0/163.0	60.1/ 17.1	3.6	-	-	-	-	N	J (21)
KAM*078*18NL	03/18	18.29.37	50.6/156.7	65.2/ 23.1	4.7	3.5	3.5	33	27	N	I (19)
OKH*078*19NL	03/18	19.17.25	54.0/150.0	60.7/ 26.2	3.7	-	-	-	-	N	J (19)
KIR*078*19NL	03/18	19.54.18	41.0/ 72.0	41.4/ 89.9	3.2	-	-	-	-	N	J (19)
CAU*079*03NL	03/19	03.34.31	42.7/ 38.1	24.4/125.6	3.9	2.7	3.0	75	167	N	I (19)
SIN*080*10NL	03/20	10.54.35	38.0/ 73.0	44.2/ 91.8	3.9	-	-	-	-	N	J (19)
KUR*080*14NL	03/20	14.08.12	47.0/154.0	68.1/ 26.2	4.0	-	-	-	-	N	J (20)
SIN*080*21NL	03/20	21.47.55	40.0/ 90.0	46.0/ 84.0	3.4	-	-	-	-	N	J (17)
EKZ*088*04NL	03/28	04.21.57	49.7/ 78.2	38.0/ 75.6	5.2	2.9	2.8	3.6	3.1	0	PX(18)
EKZ*307*01NL	11/02	01.26.58	49.9/ 78.8	38.2/ 74.9	6.2	3.8	3.7	1.7	1.2	0	PX(21)
EKZ*345*04NL	12/10	04.26.58	49.8/ 78.1	37.9/ 75.5	5.7	4.0	3.2	9.2	10	0	PX(20)
KUR*153*00NL	06/01	00.18.13	48.0/154.0	67.2/ 25.8	3.9	3.3	3.3	99	110	N	L (15)
CKZ*153*01NL	06/01	01.23.26	52.0/ 70.0	32.6/ 78.5	3.6	-	-	-	-	N	L (16)

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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
MON*153*11NL	06/01	11.22.15	44.0/103.0	53.6/ 63.3	3.7	2.9	3.3	-	126	N	N (14)
KOM*153*21NA	06/01	21.43.49	55.0/164.0	62.2/ 17.0	3.8	3.2	3.1	117	80	N	L (12)
KZH*154*05NL	06/02	05.11.13	43.0/ 81.0	44.2/ 80.5	3.5	-	-	-	-	N	N (13)
SIN*154*06NL	06/02	06.30.49	42.0/ 81.0	45.0/ 81.4	3.9	3.0	3.6	85	150	N	N (17)
CHI*154*16NA	06/02	16.49.22	36.0/ 92.0	55.0/ 77.5	3.7	3.5	3.9	356	483	N	N (11)
IND*154*20NA	06/02	20.32.55	28.4/ 95.9	63.1/ 79.3	4.3	3.2C	3.4	-	45	N	P (9)
RYU*155*02NA	06/03	02.16.51	23.5/125.5	80.7/ 57.7	5.0*	4.7	4.7	76	53	N	P (14)
IRA*155*08NA	06/03	08.21.30	29.0/ 53.0	42.3/119.4	4.2	2.6	3.1	24	59	N	N (13)
IRA*156*03NA	06/04	03.37.49	30.0/ 54.0	41.9/117.5	4.2	2.6C	2.6	-	-	N	N (17)
KAM*156*07NA	06/04	07.52.38	53.0/158.0	63.2/ 21.5	4.0	3.0	-	44	-	N	L (17)
TUR*156*16NA	06/04	16.29.34	39.4/ 26.2	23.4/149.1	4.1	2.5	2.7	-	-	17	P (16)
CHI*156*23NA	06/04	23.22.18	33.0/ 97.0	59.8/ 75.5	3.5	3.1C	3.3	-	252	N	N (13)
KAM*157*04NA	06/05	04.12.54	56.2/163.1	60.9/ 17.3	4.3	3.1	3.3	38	46	N	P (11)
GRE*157*10NA	06/05	10.44.59	37.8/ 21.4	24.0/159.2	4.2	3.6	3.6	406	331	69	P (12)
IRA*157*11NL	06/05	11.17.57	34.0/ 46.0	35.0/123.8	3.9	2.8	3.4	105	163	N	N (14)
PAK*157*11NL	06/05	11.52.53	29.8/ 70.3	49.5/100.9	4.8	3.5	3.6	20	25	27	P (14)
LOM*157*19NL	06/05	19.00.12	86.5/ 38.9	26.1/ 3.7	4.4	3.0	2.8	62	50	N	P (15)
KUR*158*06NL	06/06	06.32.10	49.0/155.0	66.4/ 24.8	3.6	-	-	-	-	N	L (17)
TAI*160*10NA	06/08	10.17.44	21.0/120.2	80.6/ 63.2	4.9	4.5	4.6	66	62	N	P (13)
TRS*160*12NA	06/08	12.46.15	41.0/ 44.0	28.2/119.4	4.1	2.5	3.0	-	-	N	L (12)
BUR*160*16NA	06/08	16.08.06	19.0/ 94.0	70.2/ 86.4	4.3	3.7	3.9	70	111	N	N (12)
TIB*160*23NA	06/08	23.10.12	29.5/ 92.3	60.4/ 81.6	4.7	3.9	4.0	46	49	64	P (12)
CRE*161*07NA	06/09	07.42.20	34.3/ 26.5	27.9/151.8	4.9	4.0	4.1	233	199	N	P (9)
PAK*162*11NL	06/10	11.29.11	28.2/ 66.5	49.1/105.7	4.5	3.8	3.8	104	-	N	P (15)
KUR*162*19NL	06/10	19.21.53	43.0/150.0	71.0/ 30.4	3.7	2.8	-	-	-	N	L (17)

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LIST OF EVENTS USED FOR EVALUATION
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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
IRA*162*19NL	06/10	19.31.42	32.9/ 46.3	36.1/124.4	4.0	3.0	3.5	109	173	N	P (18)
KAM*163*14NL	06/11	14.14.01	53.0/160.0	63.5/ 20.2	3.3	2.7	-	163	-	N	L (15)
KUR*163*23N1	06/11	23.23.04	48.0/152.0	66.7/ 27.2	4.0	-	-	-	-	N	L (19)
KUR*163*23N2	06/11	23.33.44	47.0/152.0	67.7/ 27.6	4.3	-	-	-	-	N	L (19)
KUR*164*00NL	06/12	00.19.16	44.0/148.0	69.5/ 31.5	3.7	-	-	-	-	N	L (19)
IRA*164*13NL	06/12	13.34.01	33.1/ 46.3	35.9/124.2	5.4	4.7	5.3	199	287	N	P (17)
KAM*164*22NA	06/12	22.37.38	53.0/162.0	63.8/ 18.9	3.7	-	-	-	-	N	L (16)
IRA*165*00NL	06/13	00.55.37	33.1/ 46.3	35.9/124.2	5.1	4.1	4.6	137	181	N	P (12)
KAM*165*04NL	06/13	04.53.30	55.0/162.0	61.9/ 18.3	3.8	-	-	-	-	N	L (12)
CAU*166*00NL	06/14	00.49.54	40.1/ 51.9	32.5/110.8	4.7	3.7	3.2	74	48	47	P (15)
IRA*166*04NL	06/14	04.34.28	33.0/ 46.1	36.0/124.6	5.3	3.9	4.4	46	55	N	P (17)
KOM*166*10NL	06/14	10.27.50	57.0/164.0	60.3/ 16.5	3.6	-	-	-	-	N	L (11)
IRA*166*12N1	06/14	12.35.05	27.0/ 56.0	45.3/117.5	3.6	-	-	-	-	N	N (12)
ITA*166*18NL	06/14	18.55.53	43.7/ 13.4	17.2/173.8	4.5*	4.0	4.3	839	953	14	P (15)
ITA*166*21NL	06/14	21.01.00	43.7/ 13.5	17.2/173.6	4.3*	2.8	3.3	88	164	6	P (13)
GRE*167*00NL	06/15	00.33.24	38.3/ 22.2	23.6/157.4	4.9	4.2	4.3	462	337	26	P (16)
KAM*168*09NL	06/16	09.54.41	56.0/161.0	60.8/ 18.6	4.1	-	-	-	-	N	L (11)
KAM*168*22NB	06/16	22.12.12	53.0/157.0	63.0/ 22.1	3.6	-	-	-	-	N	L (15)
IRA*168*23NL	06/16	23.22.27	34.0/ 46.0	35.0/123.8	3.7	3.0	3.2	144	166	N	N (14)
AUS*169*09NL	06/17	09.02.48	48.3/ 14.5	12.7/169.0	4.3*	2.8	2.6	95	42	N	P (11)
KUR*169*19NL	06/17	19.18.21	44.2/149.1	69.6/ 30.6	4.6	3.4	3.5	24	32	64	P (17)
TIB*170*04NL	06/18	04.30.47	33.0/ 83.0	53.0/ 87.1	4.3	3.8	3.9	113	133	N	N (16)
KUR*170*09NL	06/18	09.10.54	48.0/154.0	67.2/ 25.8	3.9	-	-	-	-	N	L (15)
SIN*170*09NA	06/18	09.18.49	40.0/ 73.0	42.6/ 90.0	4.3	-	-	-	-	N	L (15)
TUR*170*22NA	06/18	22.32.52	39.0/ 31.0	25.2/141.1	4.4	2.6	3.0	27	50	N	L (6)

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LIST OF EVENTS USED FOR EVALUATION
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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
KUR*171*18NA	06/19	18.07.53	43.8/151.5	70.6/ 29.1	4.5	3.7	3.5	55	39	N	P (14)
KUR*171*22NL	06/19	22.41.42	48.0/157.0	67.8/ 23.8	4.1	2.9	-	32	-	N	L (18)
FRS*172*09NL	06/20	09.18.09	52.0/131.0	57.5/ 39.2	3.7	2.7	2.9	-	71	N	L (13)
KAS*172*15NA	06/20	15.34.37	32.0/ 75.0	50.0/ 94.9	3.6	-	-	-	-	N	N (10)
TUR*173*05NL	06/21	05.06.17	40.2/ 30.0	23.8/141.6	4.1	3.3	3.1	165	103	N	P (15)
KAM*173*10NL	06/21	10.42.45	54.0/161.0	62.7/ 19.2	4.3	2.7	-	-	-	N	L (9)
TUR*175*04NA	06/23	04.25.27	41.0/ 30.0	23.0/140.8	3.7	2.8	3.1	232	256	N	L (19)
GRE*175*07NA	06/23	07.18.14	37.0/ 21.0	24.7/160.4	3.4	2.4	2.6	218	224	N	N (18)
IRA*175*08NL	06/23	08.39.36	32.9/ 46.2	36.1/124.5	4.6	3.2	3.8	46	75	40	P (17)
YUG*177*04NL	06/25	04.59.19	44.0/ 15.9	17.1/167.9	3.7*	2.5	2.3	130	94	N	P (18)
HNK*177*07NL	06/25	07.55.45	36.3/ 69.6	43.9/ 96.4	4.7	4.4	4.2	387	165	46	P (18)
KAM*177*17NL	06/25	17.35.50	54.0/160.0	62.6/ 19.9	4.1	3.3	3.6	79	139	N	L (19)
TAI*178*08NL	06/26	08.08.25	21.1/120.3	80.6/ 63.1	5.0	4.8	5.1	130	178	N	P (19)
KAM*178*17NL	06/26	17.32.32	56.0/158.0	60.3/ 20.5	3.6	-	-	-	-	N	L (18)
HNK*178*20NL	06/26	20.59.03	36.0/ 69.0	43.8/ 97.2	3.7	2.9	2.8	125	-	N	N (19)
PAK*179*06NL	06/27	06.39.44	29.7/ 70.3	49.6/100.9	5.5	4.9	4.6	74	57	N	P (11)
BUR*179*09NL	06/27	09.05.53	26.2/ 96.6	65.3/ 80.1	4.4	3.9	4.2	84	156	23	P (14)
PAK*179*10NL	06/27	10.48.56	29.7/ 70.3	49.6/100.9	5.2*	4.4	3.9	49	31	9	P (18)
WRS*179*12NL	06/27	12.20.36	51.0/ 47.0	22.1/100.0	3.5	-	-	-	-	N	L (17)
HNK*179*15NL	06/27	15.55.35	36.3/ 69.5	43.9/ 96.5	5.1	4.4	3.8	133	44	53	P (20)
YUG*180*01NA	06/28	01.43.56	43.0/ 20.5	18.8/157.7	4.6*	2.6	3.1	22	46	N	P (17)
CHI*180*03NA	06/28	03.09.59	33.0/ 91.0	56.9/ 80.4	3.6	3.0	3.3	119	221	N	N (15)
KOM*180*04AL	06/28	04.48.22	56.0/165.0	61.4/ 16.1	4.2	2.8	-	22	-	N	L (10)
KOM*180*06NL	06/28	06.00.22	55.0/164.0	62.2/ 17.0	3.4	-	-	-	-	N	L (15)
CYP*180*08NA	06/28	08.16.55	35.0/ 32.0	29.2/142.7	4.3	-	-	-	-	N	N (14)

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LIST OF EVENTS USED FOR EVALUATION
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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
UAR*180*09NA	06/28	09.49.35	27.6/ 33.8	36.7/144.7	5.6	4.6	4.8	140	185	15	P (17)
KAM*180*14NA	06/28	14.58.49	53.0/161.0	63.7/ 19.5	3.9	2.8	-	-	-	N	L (15)
KAZ*181*00NL	06/29	00.41.02	54.0/ 69.0	30.9/ 76.2	3.7	2.4	-	64	-	N	L (15)
AFG*181*03NL	06/29	03.32.11	38.9/ 71.4	42.7/ 92.4	4.6*	3.9	3.8	71	74	53	P (17)
TAI*182*18NL	06/30	18.57.43	24.3/121.1	78.1/ 60.9	4.9	4.9	5.4	135	385	N	P (19)
IRA*182*20NL	06/30	20.31.33	30.0/ 53.0	41.4/118.7	4.0	2.8	2.7	55	43	N	N (18)
KOM*183*02NL	07/01	02.10.18	54.0/166.0	63.5/ 16.1	3.4	-	-	-	-	N	L (17)
IRA*184*12NL	07/02	12.56.07	30.1/ 50.8	40.4/121.1	5.4	4.8	5.3	-	558	31	P (19)
IRA*184*14NL	07/02	14.05.06	30.0/ 50.8	40.5/121.2	4.6	3.3	3.3	46	43	31	F (20)
IRA*185*02NL	07/03	02.10.00	30.1/ 50.8	40.4/121.1	5.0	4.0	2.8	63	-	38	P (7)
IRA*185*12NL	07/03	12.31.05	30.0/ 53.0	41.4/118.7	4.0	2.8	-	41	-	N	N (13)
IRA*185*21NL	07/03	21.38.22	30.0/ 51.0	40.6/121.0	5.1	3.8	4.2	59	96	43	P (19)
TUR*186*06NL	07/04	06.17.25	41.0/ 33.0	24.0/135.7	3.4	2.8	2.5	385	254	N	L (17)
KAM*186*13NL	07/04	13.52.19	55.0/163.0	62.1/ 17.7	4.4	3.2	-	-	-	N	L (14)
KUR*186*21NL	07/04	21.47.57	49.0/151.0	65.6/ 27.5	3.6	2.7	-	-	-	N	L (13)
SIN*187*01NL	07/05	01.09.53	44.6/ 81.1	43.1/ 78.9	4.6	3.9	4.5	91	155	N	P (19)
SIN*187*04NL	07/05	04.09.49	43.6/ 87.9	47.0/ 74.6	4.3	3.1	3.0	29	25	N	P (14)
IRA*187*16NL	07/05	16.29.27	31.0/ 52.0	40.1/119.0	4.0	3.4	3.3	145	176	N	N (16)
IRA*187*21NL	07/05	21.41.08	30.0/ 54.0	41.9/117.5	4.1	2.8	2.8	-	38	N	N (20)
KAZ*188*01NA	07/06	01.02.58	49.7/ 78.0	37.9/ 75.7	4.4	-	-	-	-	0	PX(18)
IRA*188*05NL	07/06	05.41.43	27.0/ 55.0	44.9/118.6	3.1	2.8	-	260	366	N	N (15)
KAM*189*05NL	07/07	05.13.06	56.0/163.0	61.1/ 17.4	3.7	2.7	3.0	78	-	N	L (17)
CHI*189*23NL	07/07	23.43.41	32.0/102.0	63.0/ 72.2	3.7	3.7	3.7	-	311	N	N (17)
GRE*190*05NL	07/08	05.46.14	41.6/ 23.6	20.7/152.3	4.7	2.7	2.7	22	16	28	P (16)
KUR*190*21NL	07/08	21.07.27	48.0/151.0	66.5/ 27.9	4.2	3.1	3.1	34	36	N	L (20)

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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
MED*191*13NL	07/09	13.21.22	36.0/ 19.0	25.4/164.5	4.0	2.5	3.0	-	111	N	L (18)
SIN*192*19NA	07/10	19.03.33	43.4/ 88.6	47.5/ 74.3	4.7	3.7	3.1	48	21	N	P (19)
AFG*193*04NL	07/11	04.20.41	37.0/ 72.0	44.5/ 93.6	4.2	-	-	-	-	N	L (14)
KUR*193*06NL	07/11	06.58.21	48.4/154.5	66.9/ 25.4	5.2	4.0	-	44	-	62	P (18)
KAM*193*08NA	07/11	08.53.49	55.0/163.0	62.1/ 17.7	3.6	-	3.0C	-	-	N	L (14)
IRA*193*15NL	07/11	15.33.48	32.0/ 60.0	42.8/109.5	3.7	2.8	2.9	-	136	N	N (17)
IRA*193*22NL	07/11	22.49.02	36.1/ 45.7	33.1/122.4	4.7	3.8	3.5	111	-	N	P (18)
KUR*194*00NL	07/12	00.14.27	49.3/155.4	66.2/ 24.4	5.2	4.2	3.8	48	18	N	P (20)
PAK*194*01NL	07/12	01.21.18	33.0/ 73.0	48.2/ 95.9	3.5	-	-	-	-	N	N (18)
KUR*194*20NL	07/12	20.14.51	49.0/154.0	66.2/ 25.5	3.7	-	-	-	-	N	L (17)
TIB*195*05NL	07/13	05.27.44	31.0/ 89.0	57.6/ 83.4	3.9	-	3.7	-	122	N	N (17)
KUR*195*15NL	07/13	15.05.44	44.0/150.0	70.0/ 30.1	4.2	3.5	3.3	72	47	N	N (18)
PAK*195*18NL	07/13	18.50.53	28.0/ 63.0	47.6/109.4	3.7	3.3	-	165	-	N	N (15)
TAI*195*23NL	07/13	23.02.25	22.0/123.0	81.0/ 60.4	3.8	3.7	4.0	120	254	N	N (17)
TUR*196*04NL	07/14	04.33.45	36.0/ 31.0	27.9/143.6	3.9	-	-	-	-	N	N (20)
IRA*196*13NL	07/14	13.04.12	30.1/ 50.8	40.4/121.1	4.4	2.8	3.4	38	77	34	P (17)
IRA*196*13N2	07/14	13.18.11	30.0/ 51.0	40.6/121.0	3.9	2.7	2.9	-	-	N	N (17)
IRA*196*17NL	07/14	17.49.13	30.0/ 51.0	40.6/121.0	3.4	-	2.9	-	138	N	N (17)
RYU*196*18NL	07/14	18.50.33	30.0/132.0	77.4/ 49.4	3.9	3.1C	-	-	-	N	L (17)
KRG*197*00NL	07/15	00.35.52	43.0/ 78.0	42.8/ 82.9	3.8	2.9	-	60	-	N	N (17)
RYU*197*02NL	07/15	02.15.42	24.2/125.1	79.9/ 57.7	5.1	4.6	4.3	49	36	29	P (17)
KUR*197*09NL	07/15	09.51.51	47.0/152.0	67.7/ 27.6	4.4	-	-	-	-	N	L (17)
KAM*197*13NL	07/15	13.50.04	53.0/157.0	63.0/ 22.1	3.7	2.9C	-	-	-	N	L (15)
KUR*197*17NL	07/15	17.25.37	46.0/149.0	67.9/ 30.0	3.5	-	-	-	-	N	L (16)
TIB*198*02NL	07/16	02.20.24	32.5/ 95.9	59.7/ 76.8	5.2	4.3	4.6	-	48	N	P (15)

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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AP	AL	Z	NOTES
TUR*198*02NL	07/16	02.46.51	38.3/ 43.3	30.2/123.3	4.9	4.4	4.7	511	657	40	P (15)
TIR*198*03NL	07/16	03.40.00	32.6/ 35.8	59.5/ 76.8	4.7	3.8	4.1	-	50	N	P (18)
TAI*198*13NL	07/16	13.48.05	23.7/121.3	78.7/ 61.0	4.6	4.5	4.2	120	48	N	P (18)
KAM*198*20NA	07/16	20.04.04	54.4/162.9	62.6/ 17.9	4.2	3.2	-	50	-	N	P (19)
MED*199*03NL	07/17	03.14.05	34.0/ 30.0	29.5/146.4	3.9	2.7	3.0	86	147	N	L (19)
KAM*199*08NL	07/17	08.28.52	55.0/159.6	61.5/ 19.8	5.3	3.2	4.2	40	34	N	P (18)
KAM*199*11NL	07/17	11.11.46	57.0/162.0	60.0/ 17.7	3.3	-	-	-	-	N	L (18)
MED*199*16NL	07/17	16.15.28	35.0/ 22.0	26.8/159.5	3.4	3.0	2.6	390	257	N	N (18)
KAM*199*20NL	07/17	20.50.54	55.1/159.5	61.4/ 19.8	4.5	-	3.0	-	18	N	P (17)
SIN*200*03NL	07/18	03.27.07	39.0/ 77.0	45.3/ 87.4	4.0	2.8	3.1	-	47	N	N (18)
CKZ*200*06NL	07/19	06.04.53	51.0/ 66.0	31.3/ 82.9	3.7	2.6	-	80	-	N	L (15)
GRE*200*13NL	07/19	13.45.48	41.6/ 23.8	20.8/151.9	4.0	2.8	3.1	124	165	N	P (18)
TIB*202*10NL	07/20	10.04.18	28.0/ 91.0	61.1/ 83.7	3.9	-	-	-	-	N	N (11)
CHI*203*16NL	07/21	16.11.33	28.8/102.3	65.8/ 73.9	4.8	4.2	4.1	91	61	N	P (16)
WRS*204*05NL	07/22	05.10.40	44.9/ 36.9	22.1/124.3	4.6	4.1	3.7	380	187	N	P (18)
TIB*204*16NL	07/22	16.41.04	31.4/ 91.5	58.5/ 81.1	5.5	5.3	6.1	211	714	N	P (17)
TIB*204*21NL	07/22	21.00.09	31.4/ 91.4	58.4/ 81.2	4.7	3.1	3.8	-	27	N	P (17)
MED*205*18NL	07/23	18.17.25	33.0/ 24.0	29.1/157.0	3.9	2.8	2.6	87	61	N	L (17)
TIB*205*23NL	07/23	23.41.55	31.0/ 91.0	58.6/ 81.8	3.6	-	3.5	-	193	N	N (16)
TUR*206*10NL	07/24	10.22.23	39.4/ 40.1	28.0/126.6	4.4	3.1	3.5	110	115	N	P (15)
KAM*206*13NL	07/24	13.09.26	58.0/162.0	59.0/ 17.4	4.0	3.3	-	94	-	N	L (13)
TIB*206*14NL	07/24	14.58.14	35.8/ 80.6	49.6/ 87.0	4.8	3.5	3.6	14	17	N	P (14)
CAU*208*18NL	07/26	18.57.25	40.0/ 47.0	30.4/116.7	4.0	3.2	3.3	119	96	N	N (13)
KUR*209*00NL	07/27	00.20.55	50.0/159.1	66.2/ 21.7	5.1	4.6	4.6	119	101	N	P (16)
RYU*209*16NL	07/27	16.41.30	25.4/130.5	81.0/ 52.7	5.1	4.5	4.9	67	133	N	P (15)

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EVENT NAME	DATE	ORIGIN TIME	LATITUDE N/ LONGITUDE E	DELTA/ AZIMUTH	MB	MS RAY	MS LOVE	AR	AL	Z	NOTES
AFG*211*17NL	07/29	17.10.35	32.0/ 68.0	46.6/101.4	3.8	3.6	3.4	201	231	N	N (20)
KUR*211*21NL	07/29	21.07.16	49.2/156.2	66.5/ 23.9	4.8	4.1	3.9	52	46	N	P (19)
KAM*213*06NL	07/31	06.40.28	56.2/162.9	60.9/ 17.4	4.8	3.6	3.6	36	22	N	P (19)
IRA*213*21NL	07/31	21.01.25	31.0/ 52.0	40.1/119.0	3.6	2.7	-	-	-	N	N (19)
EKZ*229*03NA	08/16	03.16.57	49.8/ 78.1	37.9/ 75.5	5.2	3.1	-	5.0	-	0	PX(15)
WKZ*233*02NZ	08/20	02.59.58	49.5/ 48.2	23.7/101.6	5.7	3.1	2.8	2.7	1.5	0	PX(18)
EKZ*246*08NL	09/02	08.56.58	50.0/ 77.7	37.6/ 75.6	5.1	-	-	-	-	0	PX(19)
SWR*277*08NL	10/03	08.59.58	46.8/ 45.0	24.1/110.9	5.8	2.9	2.7	1.3	1.1	0	PX(16)

Miscellaneous symbols which appear on the table are: an asterisk following the m_b if the m_b was recalculated using only stations at teleseismic ($>15^{\circ}$) distances; a "C" following an M_s if detection was obtained only with a chirp filter. Non-detection of an event on a particular component is indicated by no entry in the M_s column. Love wave magnitudes were not computed for the 1971 events.

The 324 events from 1972 which were successfully processed were obtained from a list 552 events originally selected for processing. Two hundred twenty-eight events were rejected as being unsuitable for further processing for the following reasons:

Lackof data or excessive time gaps	104
Parity errors, spikes, other tape problems	13
Events subsequently found to be mislocated	3
Interference from other events	83
Events originally taken from LASA or NORSAR bulletins which PDE data later showed to be deep (>50 km).	25
	228

Thus, 59% of the events initially selected for analysis were ultimately successfully processed.

The data used for noise analysis and array processing analysis were edited quasi-periodically at ten day intervals continuing the analysis of 1971 (Eyres et al., 1972). The intervals were selected so as to exclude any surface wave arrivals from known events at the array. Exceptionally long intervals of signal-free noise were edited whenever found. The data from at least one site of each noise sample were always plotted to make sure that surface waves from unreported events were not present.

A diagram of the 22-site NORSAR long-period array is shown in Figure II-1.

In contrast to the various data quality problems of last year, the data from the first seven months of 1972 were of generally high quality. This year an average of 16.5 sites were used for beam forming as opposed to 13.5 sites for 1971 data. A histogram of the number of sites for beamforming from 1972 is shown in Figure II-2.

Most data problems seemed to be associated either with "dead" or inverted channels (presumably arising from renovation of seismometer vaults) or tape errors incurred during recording of the data at SDAC (mostly in late July and early August 1972). Time gaps from transmission loss or NDPC downtime were very minor problems.

Processing of the 1971 events was done using three different passbands in an effort to determine which was the most suitable. It was decided that the passband of 0.025-0.059 Hz or 17-40 seconds would be best and was used for processing all of the 1972 events. This particular band was not used for the 1971 events, so 1971 results from the 0.020-0.059 Hz band were used in Table II-1.

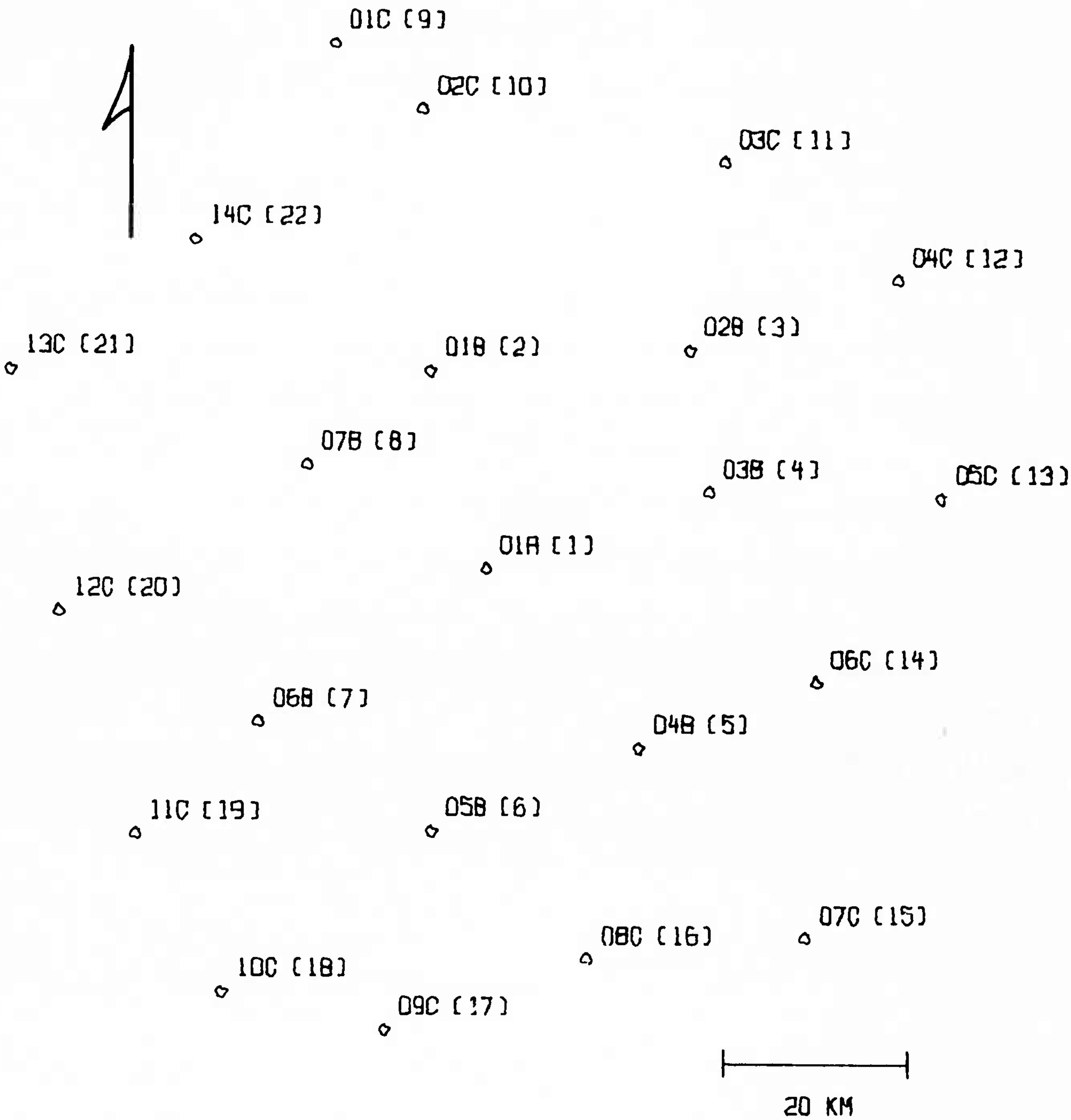


FIGURE II-1

SITE DIAGRAM OF THE NORSAR LONG-PERIOD ARRAY

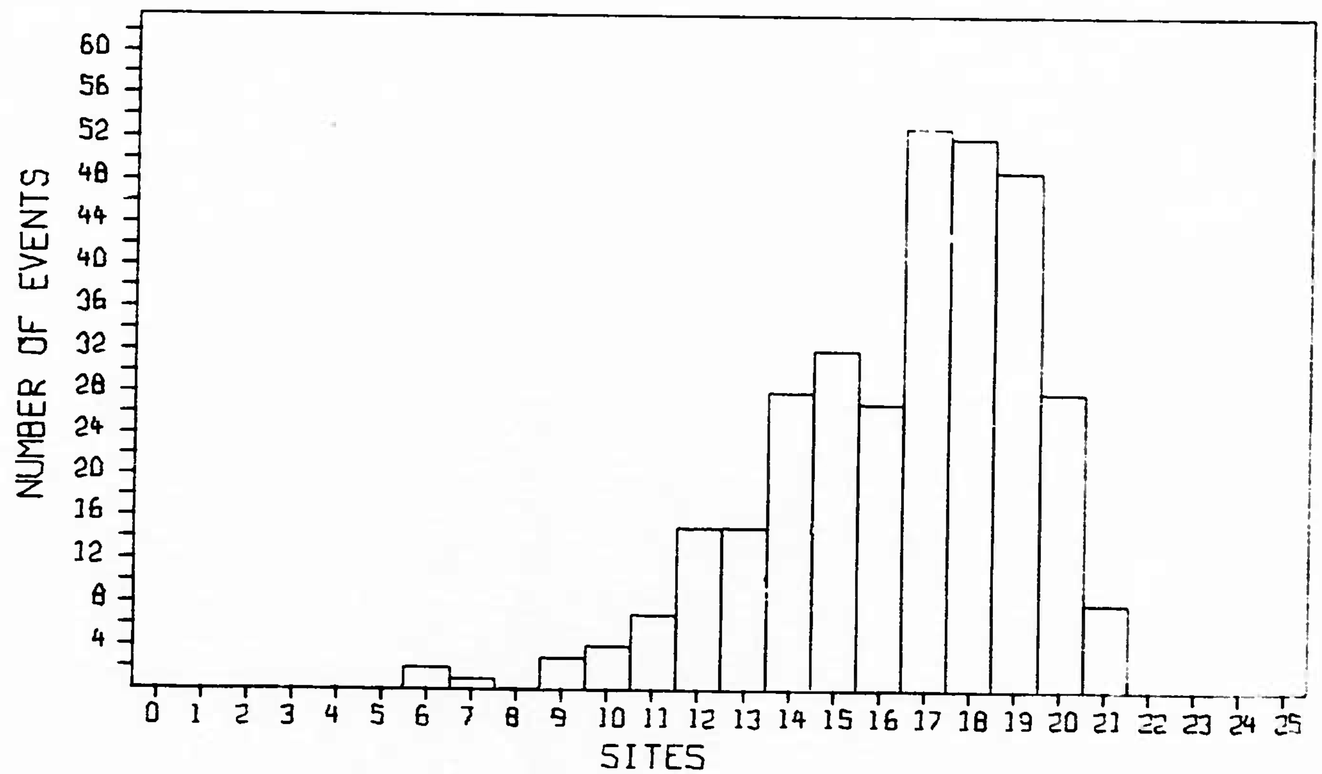


FIGURE II-2

NUMBER OF SITES INCLUDED IN ARRAY BEAM
1972 EVENTS

SECTION III

NOISE ANALYSIS

A. INTRODUCTION

The results presented here from the study of long-period noise at NORSAR are a direct continuation of the work reported on in Special Report No. 5. By combining the 1971 data reported previously with the 1972 data, approximately twenty months of noise history have been analyzed. This extensive data base has revealed the general features of the annual and seasonal variations as well as some short-term characteristics of the NORSAR noise field. The previous study also suggested some areas requiring a closer investigation, such as the correlation of noise azimuths to meteorological data and the long term changes in noise azimuth and RMS level from summer to winter. These phenomena have been further investigated and detailed results are presented in this report.

B. DATA

The 1972 data used in this study are listed in Table III-1. The data for 1971, also used in this report, are listed in Special Report No. 5.

The 1972 noise samples through 1 August 1972, with the exception of 18 February 1972, were several hours long. The samples from 18 August 1972 to 26 December 1972 were 42 minutes-40 seconds long and were used primarily to compute average RMS amplitudes to the end of 1972. The criteria for chosing these samples are given in Section II.

The 1972 data were processed in the same manner as the 1971 data; using 2.0 second sample period and 256 second segments,

TABLE III-1

1972 NORSAR NOISE SAMPLES

Day	Start Time hr:min	Length hr:min:sec	Number of available sites
5 January	13:00	6:24:00	14
5 January	19:00	6:24:00	14
13 January	8:30	3:35:00	13
19 January	4:30	4:45:52	14
30 January	6:00	5:49:52	18
10 February	18:00	4:37:30	19
18 February	5:30	0:21:08	20
26 February	7:30	6:24:00	15
8 March	22:00	2:54:56	16
28 March	22:30	7:06:40	18
8 April	10:30	5:02:56	19
23 April	6:00	4:45:52	22
17 May	5:00	1:25:20	16
27 May	15:00	3:07:44	21
3 June	21:00	4:16:00	17
15 June	17:40	3:35:00	21
7 July	21:00	2:42:08	16
13 July	3:20	2:50:40	20
23 July	14:30	2:29:30	21
1 August	14:15	3:03:28	16
18 August	20:00	0:42:40	19
28 August	1:00	0:42:40	21
6 September	10:00	0:42:40	18
17 September	8:00	0:42:40	19
28 September	14:00	0:42:40	19
17 October	10:00	0:42:40	19
27 October	22:00	0:42:40	19
6 November	8:00	0:42:40	20
15 November	23:00	0:42:40	21
26 November	20:00	0:42:40	21
6 December	17:00	0:42:40	21
26 December	15:00	0:42:40	21

cross-power matrices were formed by Fourier transforming segments, hanning, crossmultiplying the transforms and stacking the segment cross-power matrices. Dead or bad sites and segments were eliminated by examining both the time traces and the power spectra.

The data were not corrected for instrument response, but the nominal amplitude quantization value of 2.47 mμ/computer counts at 0.04 Hz was used to normalize the spectra.

Only the vertical components were used in this analysis, for the following reasons:

- The 1971 study indicated that the horizontals generally had similar noise levels but less coherence than the verticals in the 20 to 40 second band.
- The requirement that all three components be operating and free of non-seismic noise substantially reduces the number of sites usable for f-k spectral analysis.
- A visual inspection of the power spectra throughout 1972 showed that the horizontal-vertical relationship in the 20 to 40 second band had not changed from 1971.

Thus, the inclusion of the horizontals would add little to the information to be derived from the vertical components.

C. SPATIAL VARIABILITY

Special Report No. 5 showed that the NORSAR array was amplitude equalized within $\pm$ 2 dB in the 20 to 40 second band from site to site during 1971. Visual inspection of the broadband power levels (0.00 to 0.25 Hz) throughout 1972 and a check of the 1 August 1972 noise sample in the 20 to 40

second band showed that amplitude equalization among sites continues to be within ± 2 dB during 1972.

D. TIME VARIABILITY

The seasonal dependency of the noise level at NORSAR was determined by using the average vertical RMS amplitude in the 20 to 40 second band. This average was computed over the duration of each noise sample for each site and averaged over sites. The average vertical RMS noise level plotted versus day of the year is shown in Figure III-1, which includes 1971 data.

The primary feature of Figure III-1 is the seasonal variation in noise level. The noise level is nearly constant from 1 May 1971, when data were first available, to 27 November 1971 and then begins to rise and, while erratic, stays high until returning to a nearly constant level again at 10 Februar 1972. Again on 17 October 1972 the RMS level begins another erratic climb to the year's end. Thus it appears that the period between February or March and October or November has low noise levels at NORSAR, with average RMS values being 6.8 mμ in 1971 and 7.1 mμ in 1972.

An investigation of the short term noise variations in the first 80 days of 1972 was made from the noise data edited with the signals processed during this time. The noise data were typically only 1000 seconds (approximately 20 minutes) long and preceded the P arrival on site 1 vertical. The data were bandpass filtered (20-40 second band) and the RMS value then computed. Figure III-2 shows the vertical RMS level versus day. The general structure of Figure III-2 agrees with that of Figure III-1 in that maximum and minimum occur on the same day. However, the general level of Figure III-2 is higher than Figure III-1 particularly during the latter part of February and during March. Part of this may be due to the short samples of Figure III-2

FIGURE III-1

AVERAGE VERTICAL NOISE AMPLITUDE
(20-40 Sec.) AT NORSAR 1971-1972

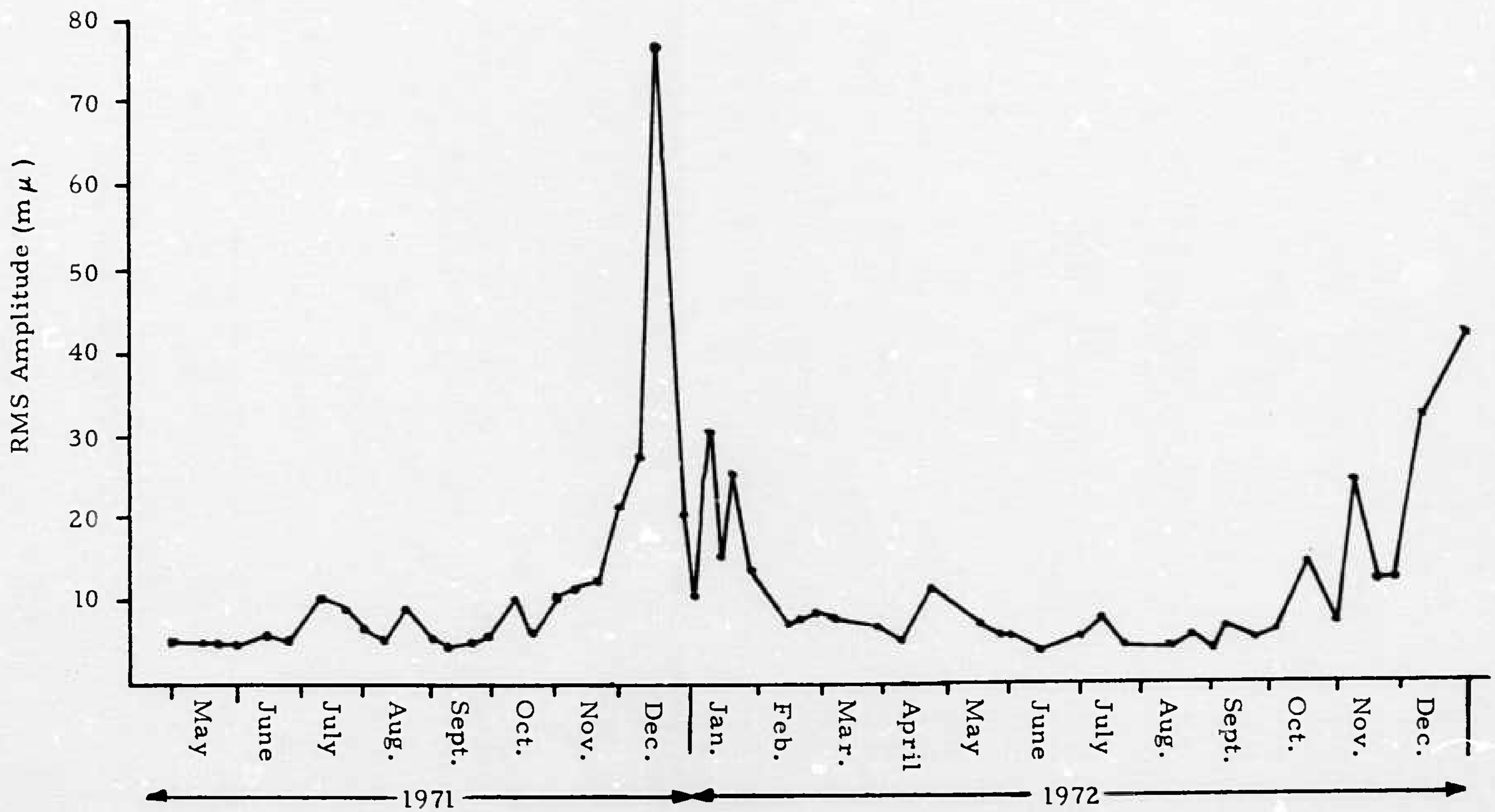
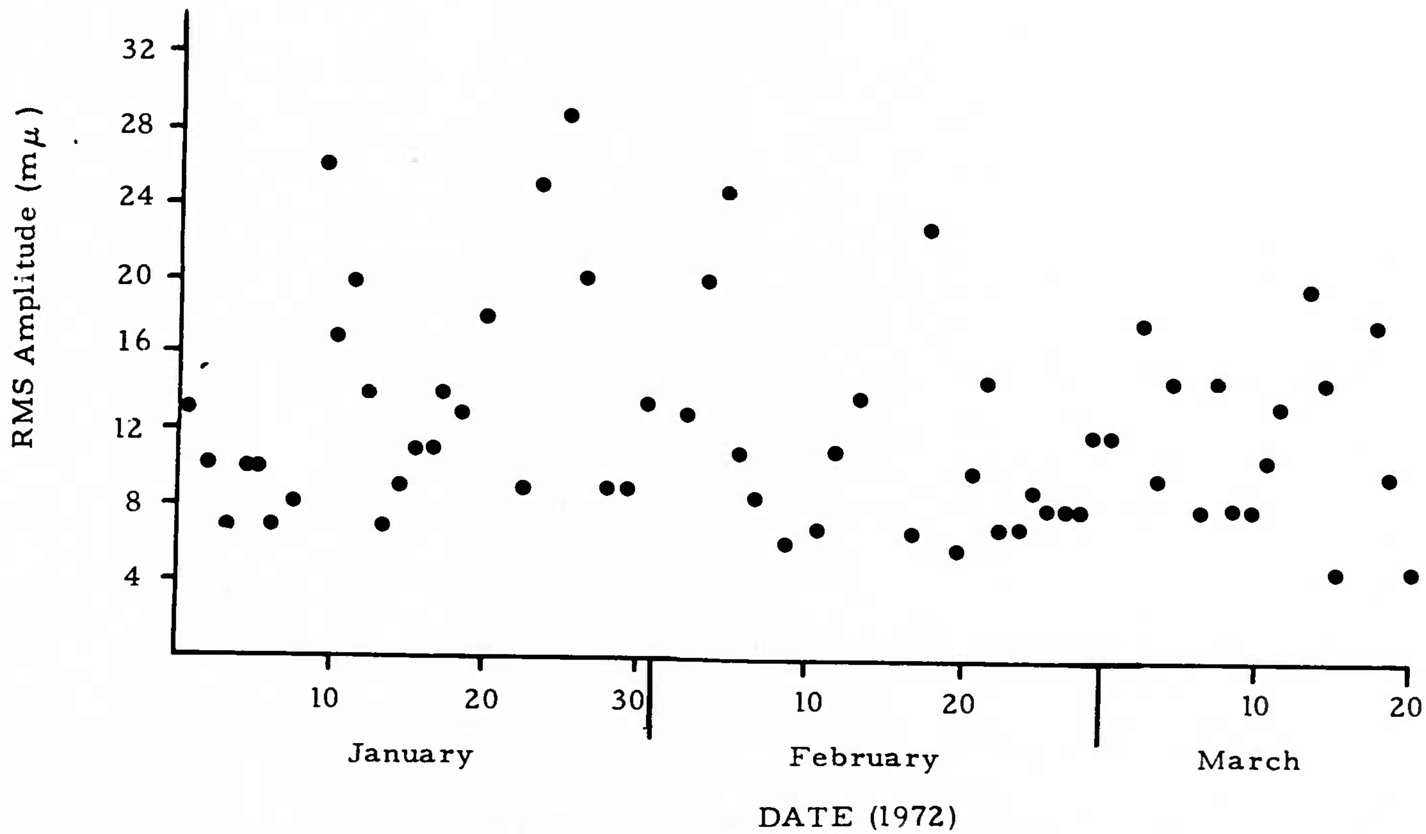


FIGURE III-2

SINGLE SITE VERTICAL NOISE AMPLITUDE (20-40 Sec.)
DURING THE FIRST THREE MONTHS OF 1972



containing some low level coda from earlier units that would be averaged out over the longer samples of Figure III-1. Figure III-2 illustrates that large short-term variations in the noise level occur during this period; clearly the NORSAR detection capability can vary by up to about 0. 5 M_s units depending on the time of occurence of a given signal.

The very high noise level on 14 December 1971 was investigated in more detail to determine the duration and character of the noise immediately preceding and following this noise sample. Data were edited, when available, from 1047Z of 13 December (day 347) to 0500Z of 15 December. The broadband (0 to 0. 25 Hz) RMS level was computed over successive 256 second gates. Figure III-3 shows a plot of the RMS level of every third gate versus time.

In Figure III-3, noise levels are fairly constant from 1100Z to 1300Z on 13 December, but after the 4 hour data gap the noise begins to increase. A noise peak occurs at 1100Z on 14 December and then gradually the noise level drops until the data are terminated at 0400Z of the following day. (A swarm of Kamchatka events on 15 December starting at 0800Z prevented editting of additional noise data.)

Over this 43 hour period, the broadband RMS level increased by a factor of 10. The noise in the 20 to 40 second band showed almost as much change, with RMS amplitudes of 16. 6 mμ at 1200Z, 13 December; 77. 2mμ at 0500Z, 14 December and 28. 2 mμ at 0400Z, 15 December. The large difference between the broadband RMS level and the 20-40 second RMS level is due to the large 6 second peak also in the spectrum during this time. The variation of the 20-40 second band, above, represents a change of 0. 65 M_s units over this 43 hour period and represents a maximum change of 1. 2 M_s units relative to the NORSAR minimum of 6. 8 mμ .

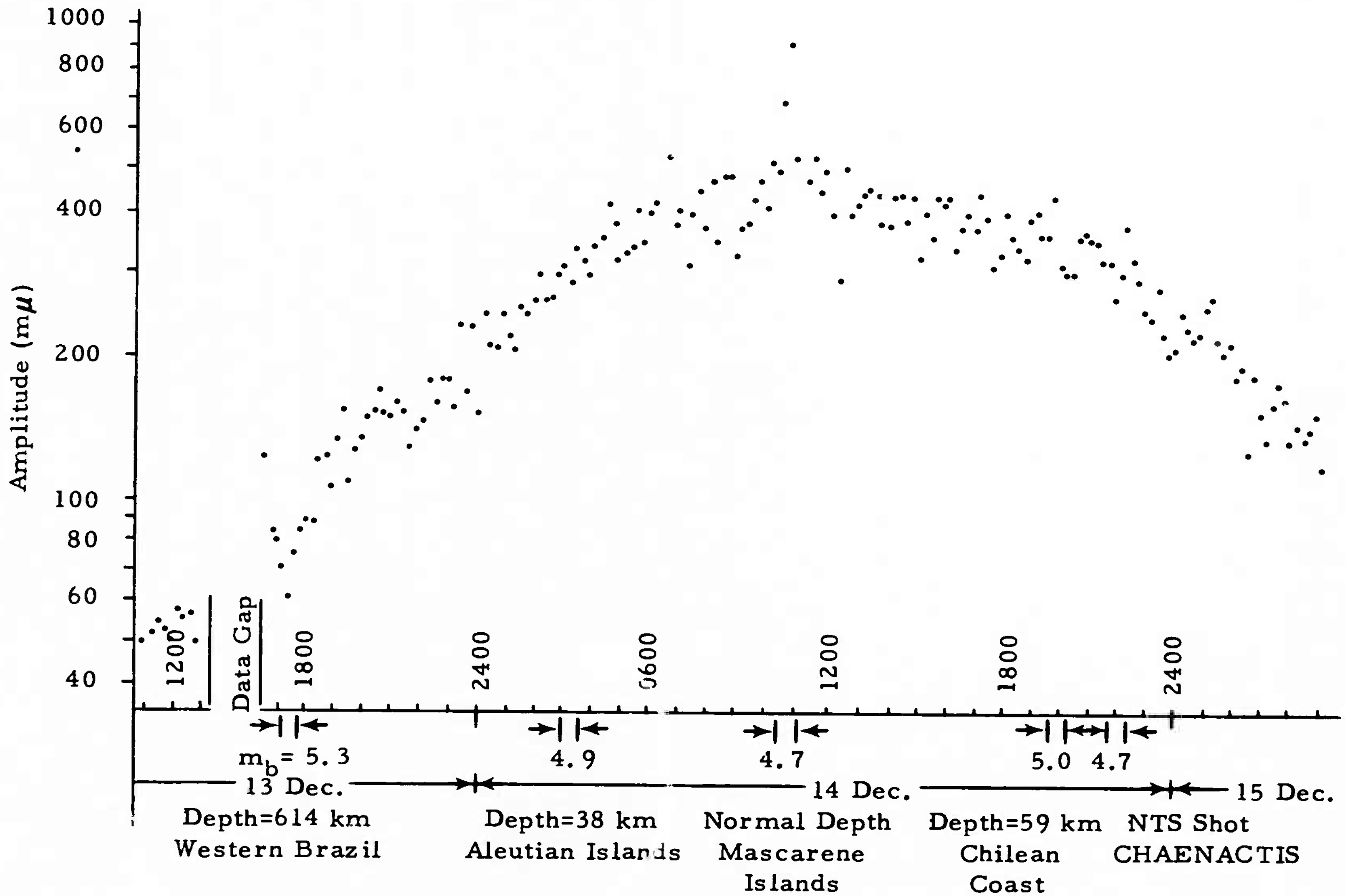


FIGURE III-3

SITE 4 VERTICAL BROADBAND RMS AMPLITUDE
DURING DECEMBER 13, 14, AND 15, 1971

Figure III-3 also shows approximate arrival times of surface waves from five events listed by NOAA-PDE with $m_b > 4.5$ and occuring in this time period. These events were not routinely processed so that beam detection data were not available, however, on the raw time traces only the Mascarene Is. event arriving at 1047Z, 14 December was definitely visible. The others are not visible probably due to their depths.

The data over this 43 hour period supplement the data in Figure III-2 in that while the day-to-day changes in RMS level may be large, the hourly change is gradual and not as sudden as Figure III-2 might suggest.

E. NOISE DIRECTIONALITY

Special Report No. 5 showed that the noise direction on 14 December appeared to be directly correlated with areas of low pressure and large swell heights in the North Atlantic. From the data used in Figure III-3, high resolution f-k spectra using maximum likelihood filters (Barnard, 1969) were generated at 0.06 Hz for the time intervals from 1047Z to 1350Z, 13 December; 0400Z to 0603Z, 14 December; and 0440Z to 0513Z, 14 December. These spectra, shown in Figure III-4, indicate a noise peak at 3.5 km/sec. which shifts clockwise from 280° to 350° to 10° azimuth over this 43 hour period.

During this time period, National Weather Service surface pressure charts and Combined Sea and Swell Height Charts were available. Figure III-5 is a map of the North Atlantic Ocean region on which the movements of the three low pressure areas present on these dates are plotted. The two areas of maximum wave heights (taken from the two wave height charts available) also are shown.

During this 43 hour period, the northernmost low pressure area (labeled C-C') and the northernmost area of maximum wave height move from west to north relative to NORSAR coincident with the west to north movement of the microseismic peak azimuth at NORSAR. This indicates that the

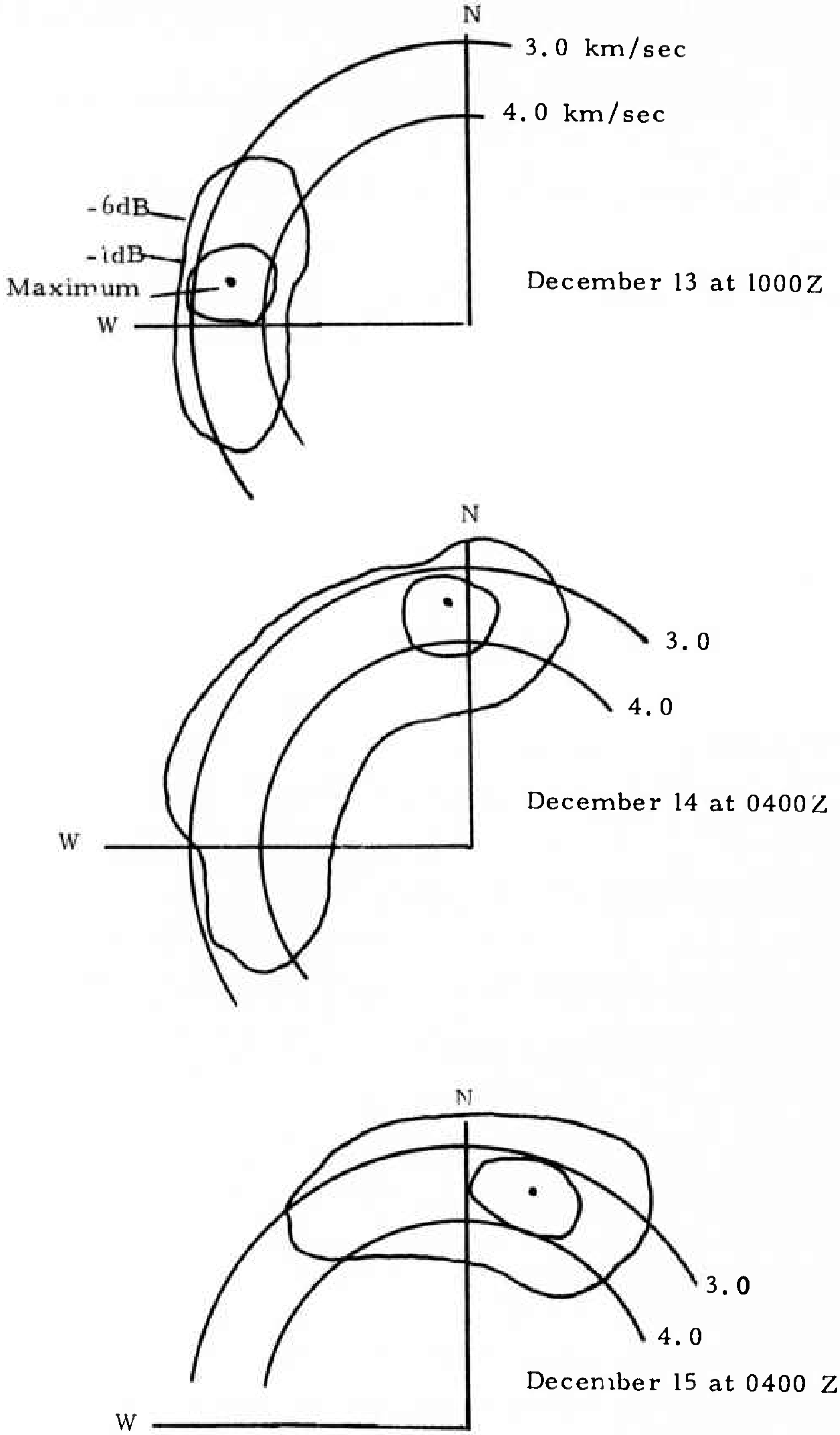


FIGURE III-4

HIGH RESOLUTION F-K SPECTRA POWER LEVELS, 13, 14 AND 15 DECEMBER 1971 AT 0.06 Hz

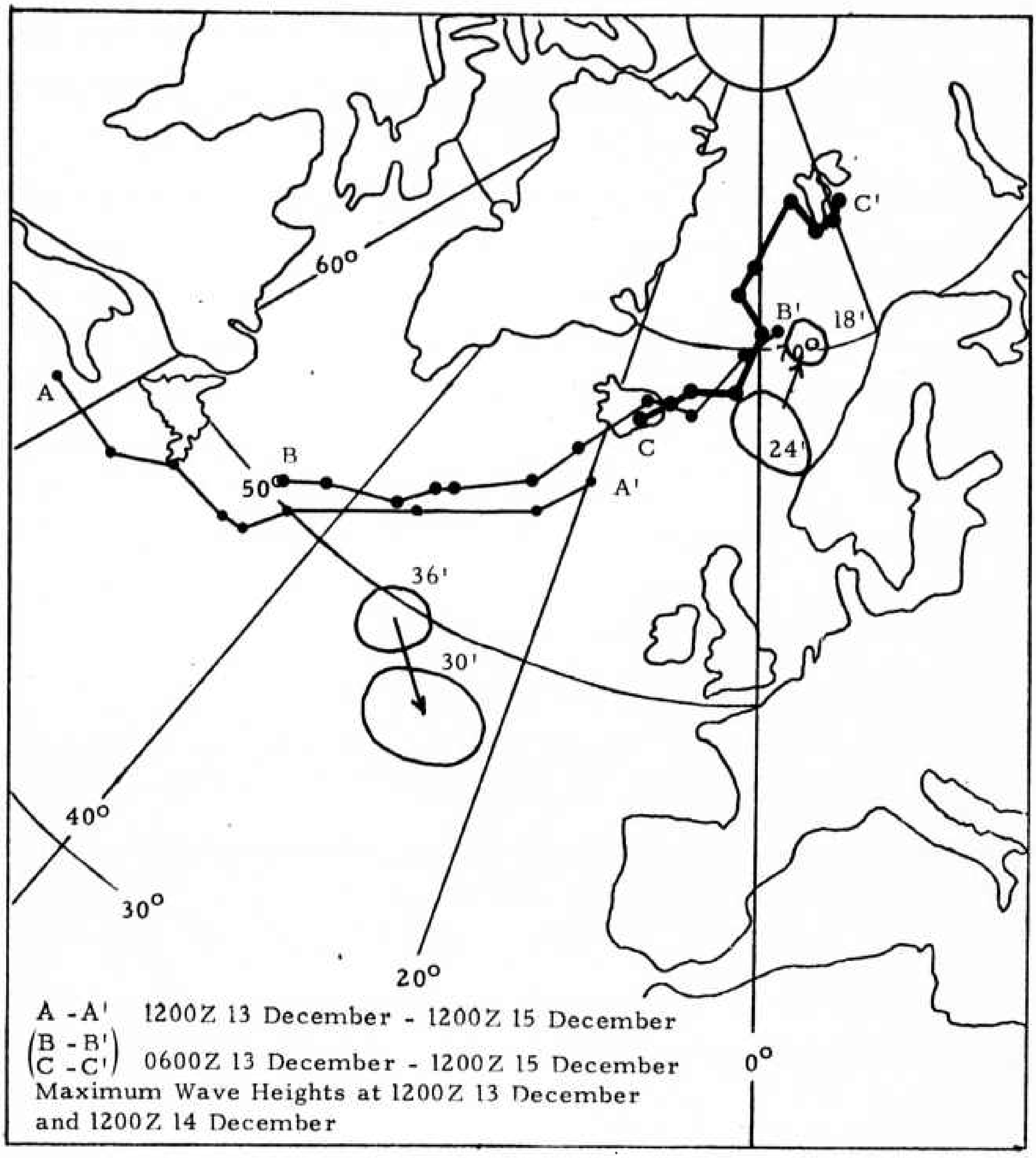


FIGURE III-5

PATHS OF LOW PRESSURE CENTERS IN 6 HOUR INTERVALS AND MAXIMUM WAVE HEIGHTS 13-15 DECEMBER 1971

observed noise azimuth is directly correlated with either the low pressure area or the area of maximum wave height.

The suggestion of a direct correlation between noise azimuth and either maximum wave height area or low pressure area was further investigated in the noise of 5 January 1972. The noise sample of 5 January consists of 11 hours of noise starting at 1300Z of 5 January (omitting the data between 1500 Z - 1600 Z which contained an event). High resolution f-k spectra at the microseismic peak frequency were generated hourly and the results by hour, frequency and peak azimuth are tabulated in Table III-2. The velocities of all peaks were near 3.5 km/sec . The significant feature of Table III-2 is the absence of a continuous range of azimuths but rather a grouping of azimuths from 285° - 290° and 350° to 0° (the same as the 13-15 December period). One value at 302° is an exception.

Low pressure centers and maximum wave height areas from the National Weather Service charts for this period are plotted in Figure III-6. The two major azimuths of 285° and 0° correlate very well with the low pressure centers although the northern low (labeled B-B') is very weak. The single peak at 302° could be due to the high seas off Iceland.

Of additional interest is the structure of the individual high resolution f-k spectra of these samples. Figure III-7 is a series of plots of the power values in the high resolution f-k spectra at a velocity of 3.5 km/sec for several of the 5 January samples. The power values are in dB relative to the peak value and plotted versus azimuth. These data show three local maximum in the spectra, at 200° to 220°, 280° to 300°, and 0° azimuth. Figure III-7 suggests that the above three azimuthal noise directions are always present in the noise spectral but at varying power levels.

TABLE III-2

HOURLY PEAK FREQUENCY AND PRIMARY SOURCE AZIMUTH OF THE MICROSEISMIC NOISE ON 5 JANUARY 1972

Hour (GMT) (Approximate)	Frequency (Hz)	Azimuth (Deg)
1300-1400	0.066	285°
1400-1500	0.066	285°
1600-1700	0.066	290°
1700-1800	0.066	0°
1800-1900	0.066	355°
1900-2000	0.062	350°
2000-2100	0.062	302°
2100-2200	0.066	358°
2200-2300	0.066	285°
2300-0030	0.066	285°

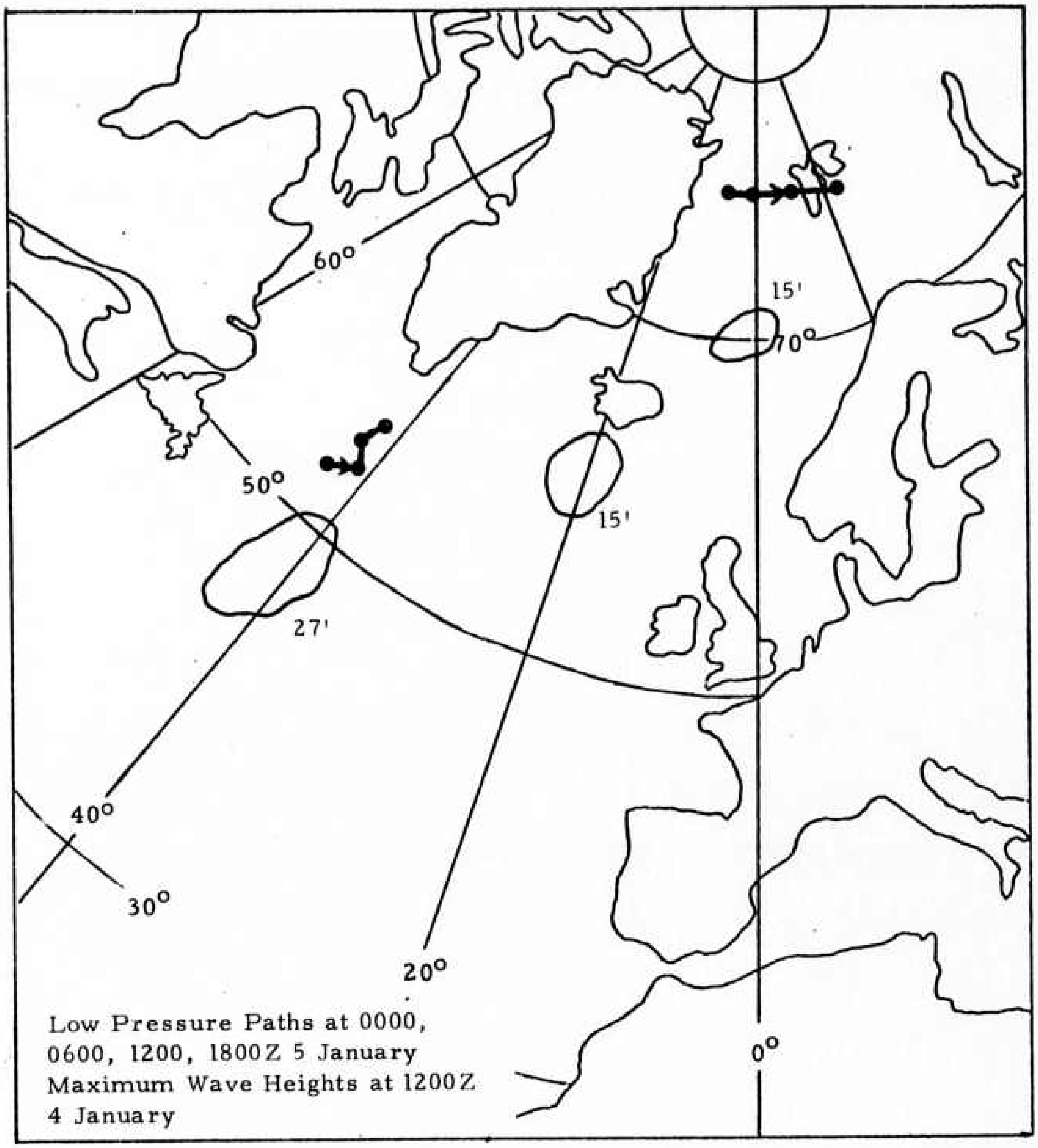


FIGURE III - 6

PATHS OF LOW PRESSURE CENTERS IN SIX HOUR INTERVALS AND MAXIMUM WAVE HEIGHTS 5 JANUARY 1972

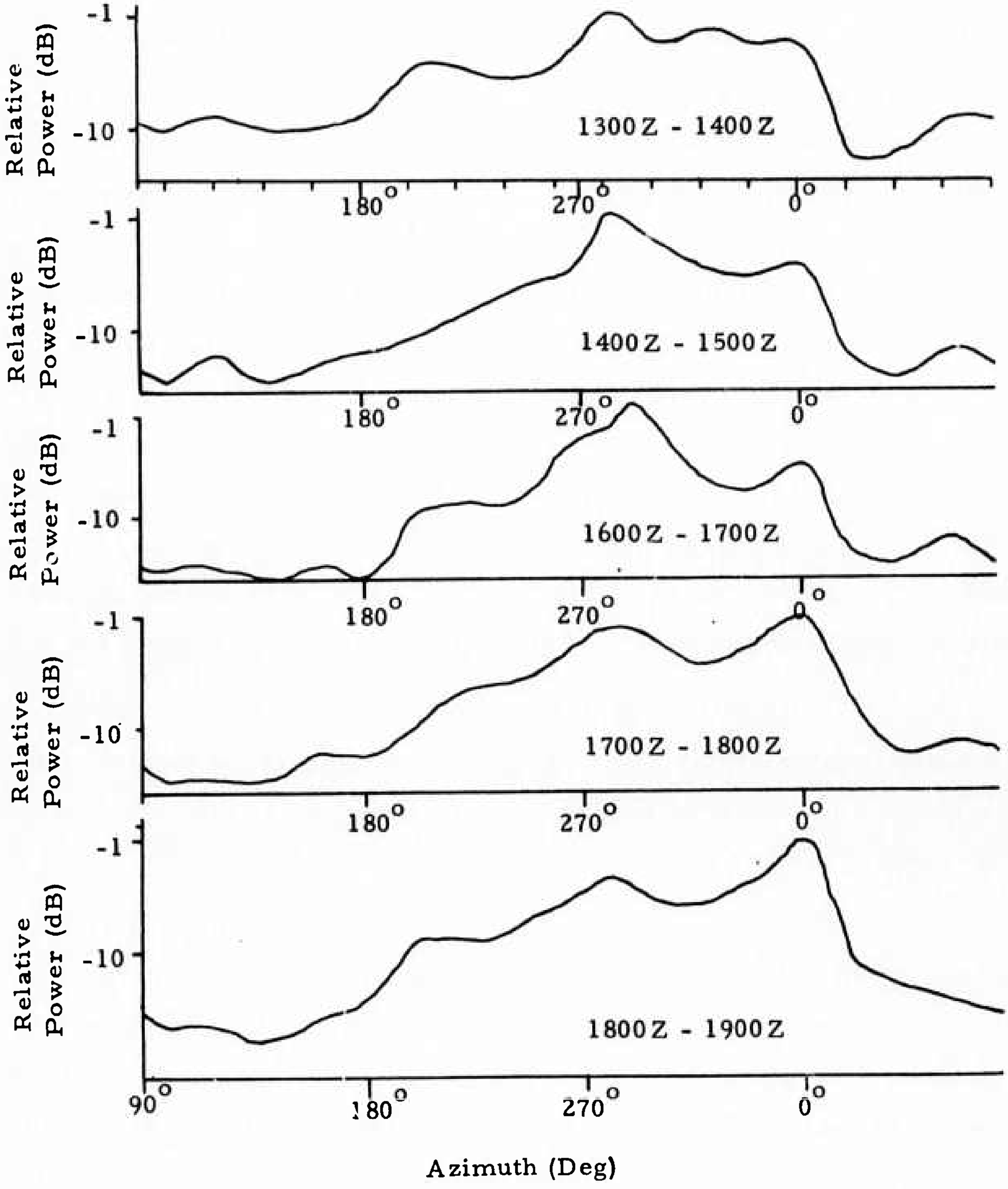


FIGURE III-7

AZIMUTHAL POWER DISTRIBUTION AT 3.5 KM/SEC. FROM 1400Z TO 1900Z ON 5 JANUARY 1972

The other noise samples of Table III-1 also tend to reinforce the suggestion of discrete noise azimuths rather than a continuous range. Table III-3 is a list of the 1972 long noise samples with the high-resolution f-k spectra power peaks listed by frequency of the peak and azimuth (all the velocities were at 3.5 km/sec). From the data of Table III-3 and the 1971 data the histogram of Figure III-8 was constructed with the number of occurences of peak power tabulated in 10° azimuthal increments. This histogram is further divided into shaded and unshaded samples. The shaded samples are data from 15 May through 8 October 1971 and 13 July through 1 August 1972 and contain all the easterly noise peak azimuths. It is of interest to note that the above time gates for easterly noise are not the same as the times of minimum noise at NORSAR so that the lowering of the noise level does not coincide with the beginning of easterly peak noise azimuths. The above time gates for easterly noise azimuths nearly correspond with the summer season and are termed the summer noise; data outside these times are called winter noise.

In the histogram of Figure III-8 there are five azimuths which contain approximately 70% of the noise peaks; 0°, 60°, 90°, 250° and 280°. Of the winter samples 80% of the noise peaks are at azimuths of 0°, 250° and 280°.

Figure III-9 shows relative power versus azimuth taken from the high-resolution f-k spectra at 3.5 km/sec for four winter samples. In all the examples shown, and in all the winter noise f-k spectra investigated one or more of the previously noted azimuths appear as primary or secondary maxima. The fact that these azimuths consistently appear in a wide variety of noise samples and winter weather conditions gives strong evidence that the winter noise has only a few discrete azimuthal directions 0°, 250° and 280°.

The existence of these discrete azimuths are of significant importance in the generation of long period noise. Because the low pressure

TABLE III-3

VERTICAL PEAK POWER AZIMUTH, FREQUENCY, AND VELOCITY BY DAY OF YEAR 1972

Date (1972)	Frequency (Hz)	Peak Azimuth (Deg.)
12 January	.066	0^{o}
19 January	.063	300^{o}
30 January	.063	283^{o}
10 February	.066	255^{o}
26 February	.066	250^{o}
8 March	.066	5^{o}
28 March	.070	285^{o}
8 April	.078	218^{o}
23 April	.063	285^{o}
17 May	.078	0^{o}
27 May	.070	255^{o}
3 June	.074	265^{o}
15 June	.055	335^{o}
7 July	.070	255^{o}
13 July	.055	93^{o}
23 July	.066	65^{o}
1 August	.059	95^{o}

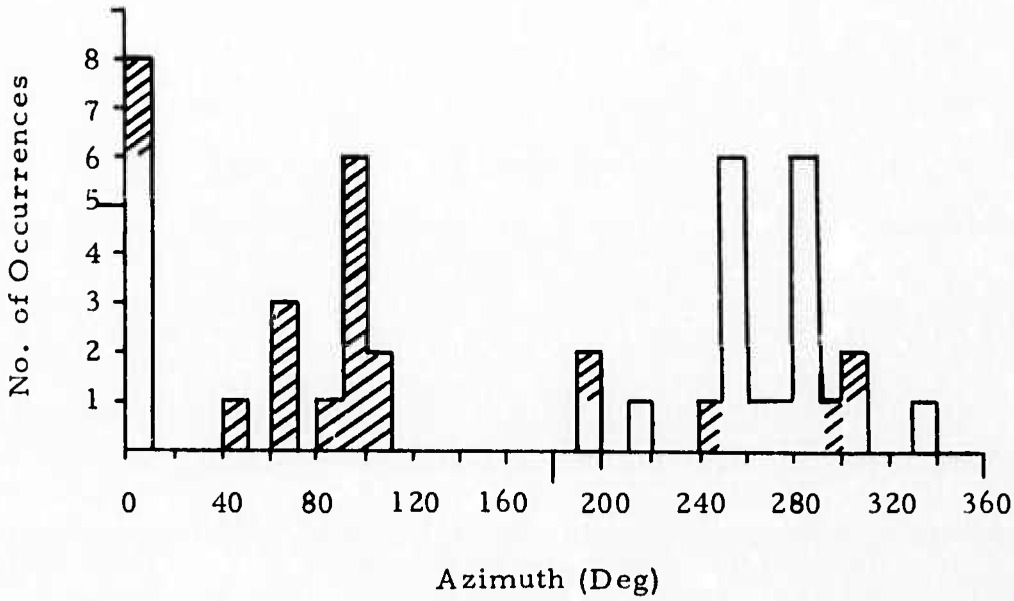


FIGURE III-8

HISTOGRAM OF VERTICAL PEAK POWER AZIMUTHS FROM NOISE SAMPLES IN 1971 AND 1972

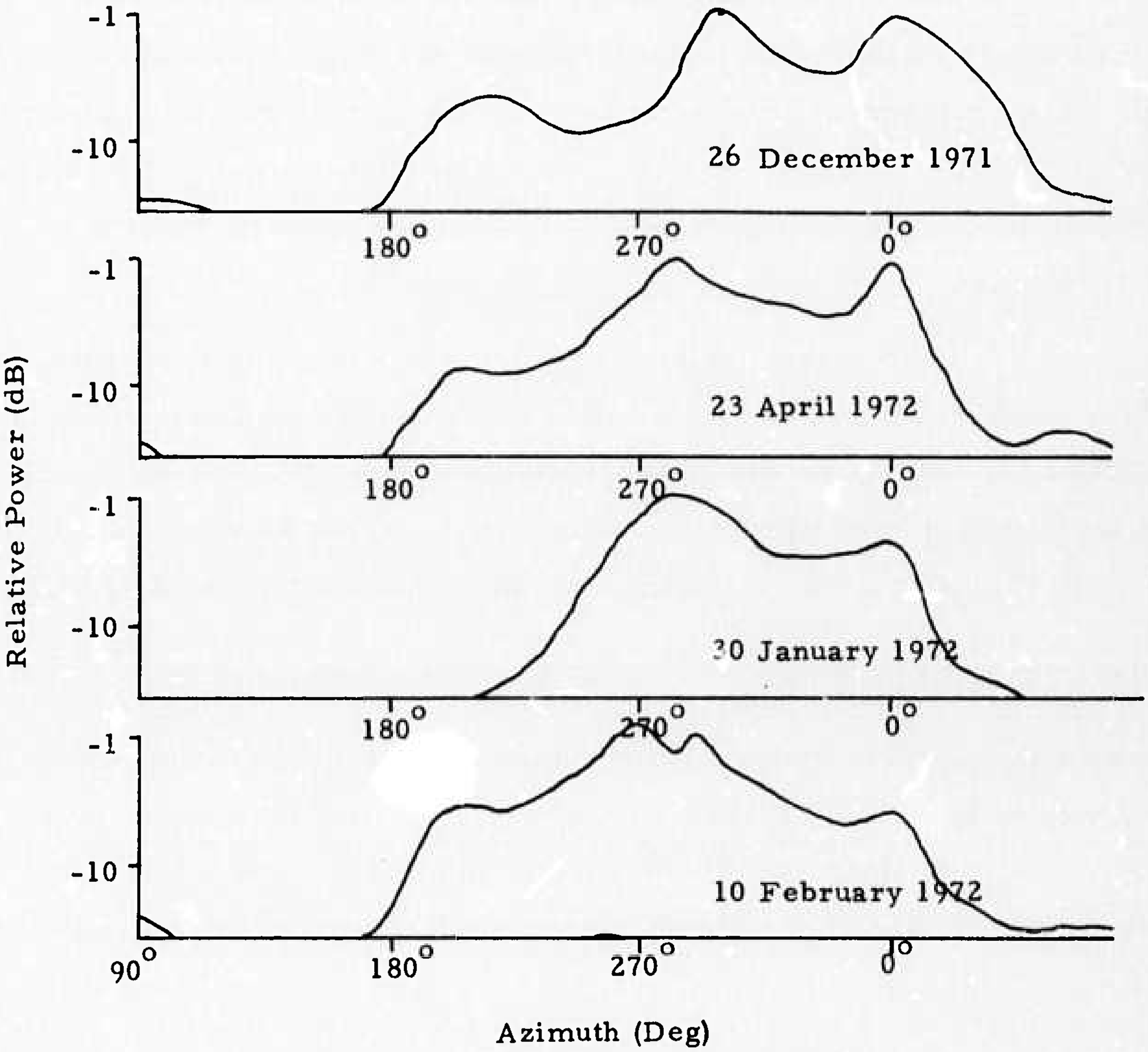


FIGURE III-9

AZIMUTHAL POWER DISTRIBUTION AT 3.5 KM/SEC.
FOR VARIOUS NOISE SAMPLES

areas and maximum wave height areas move continuously northeastward in the North Atlantic a concentration of energy coupling at various points along the Norwegian coast due to ocean bathymetry appears to be the probable factor. This effect is to be further investigated in future work.

As stated previously the summer noise samples contain all the easterly noise peak azimuths (Figure III-8). Even though the summer peaks show a predominantly easterly direction the noise is generally almost isotropic. Figure III-10 is a contoured plot of the high-resolution f-k spectra of 23 July 1972. The noise in Figure III-10 is nearly isotropic between 3.5 and 4.0 km/sec.

Note that the distinction between winter and summer noise was made on the basis of noise azimuth rather than noise level. The lowering of the RMS noise level to the base levels shown in Figure III-1 does not coincide with the change to easterly azimuths. In Figure III-1 the RMS level at 10 February 1972 is near its minimum value of 7.1 $m\mu$ but the structure of the high-resolution f-k spectra on this day (Figure III-9) shows the strong discrete noise azimuths of winter. The low RMS noise level on 10 February with the absence of an easterly noise peak suggests that the summer noise, at a comparable RMS to 10 February, can not be a constant year around background level but is due to a different generating mechanism than that of the winter noise. However, the source mechanism for summer noise is presently unknown.

In summary, the following conclusions from this noise analysis can be made:

- Site-to-site variation continues to be within $\pm$ 2dB in the 20-40 second band for 1972.

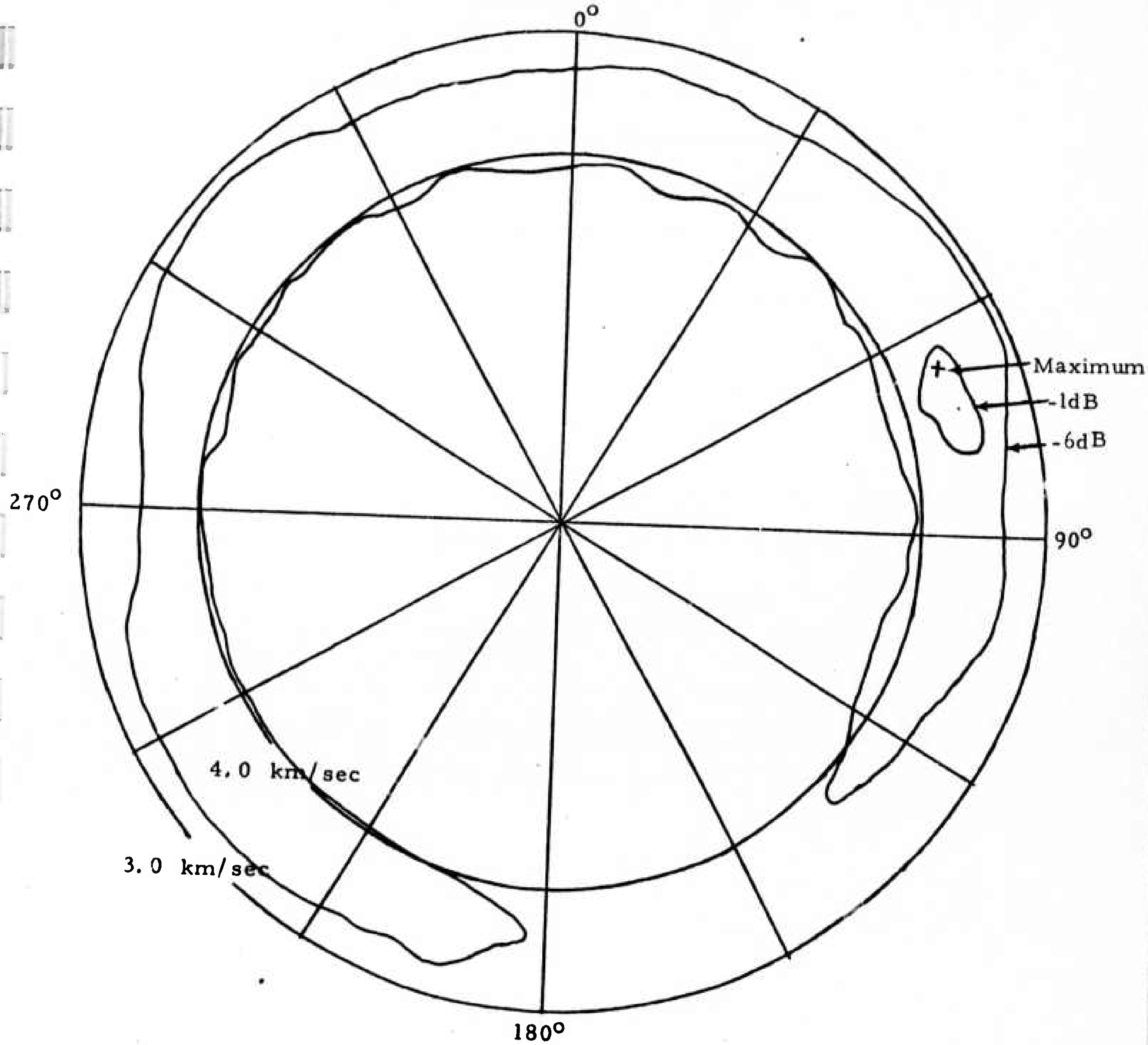


FIGURE III - 10

HIGH RESOLUTION F-K SPECTRA OF NOISE
FROM 23 JULY 1972 AT 0.06 Hz

- RMS noise levels are seasonally dependent. The first and last two months of each year are characterized by high noise levels and large changes, often occuring daily, whereas the remainder of the year has noise levels uniformly low.
- Noise levels appear as a function of the severity of North Atlantic weather conditions.
- Winter noise generally appears to be from one or more of three azimuths 0°, 250° and 280°. The reason for these preferred azimuths will be further investigated.
- Summer noise is nearly isotropic with a weak maximum to the east.
- Seasonal changes in noise azimuth are not reflected in concurrent changes in noise level. Noise azimuths show little correlation with RMS level.
- Winter detection capabilities can change by 0.50 - 0.65M_s units from day to day and can be up to 1.2M_s units higher than those observed during the summer.

SECTION IV
ARRAY PROCESSING PERFORMANCE

A. INTRODUCTION

The effectiveness of array processing at NORSAR was evaluated by comparing the performances of a conventional beamsteer (BS) processor and a multichannel Wiener filter (MCF) processor. Results from last year's work, discussed in Special Report No. 5, showed that, under winter noise conditions, MCF processing gave significantly better noise reduction than beamsteering. The purpose of the evaluation this year was to see if MCF's continued to significantly outperform beamsteering and to explore the feasibility of routinely designing and applying multichannel filters. The following analyses were undertaken to accomplish these objectives:

- Estimation of the noise rejection achieved by MCF and BS processors for various array and subarray configurations.
- Examination of the azimuthal dependence of array gains.
- Comparison of signal-to-noise ratio (SNR) improvements obtained by MCF and BS processors for several seismic events.

Multichannel filters and beamsteer processors were designed from and applied to eleven winter noise samples to measure noise reduction for four array and subarray configurations: the full array, the outer ring sites, the inner ring sites, and a special subarray of seven close sites. One of the noise samples was used to study the azimuthal dependence of array gains.

In order to test the effects of these processors on signal waveforms, MCF and BS processors were also designed and applied to four events (and their associated noise samples).

B. WINTER NOISE REJECTION BY MCF AND BS PROCESSORS

The present work on array processing performance was directed toward the noise rejection achieved by MCF and BS processors on winter noise at NORSAR, using various array and subarray configurations. Eleven typical winter samples, listed in Table IV-1, were used for the noise rejection analysis. These samples covered the period from 5 January 1972 to 8 March 1972. Note that for the last two of these samples, noise levels had returned to "summer" levels, although noise azimuths were still typical of wintertime conditions (see Section III). The shortest noise sample was five hours long (71 data segments) and the longest extended approximately 7 hours (100 segments). The time data were checked for quality and for surface waves from unreported events. The data from bad sites and the portions of the data including signals or glitches were deleted.

The MCF's were designed for only the vertical components of the Rayleigh wave. The following MCF design parameters were used to allow comparison of results to previous NORSAR and ALPA results.

- Frequency-domain design by transforming, cross-multiplying, and stacking 256-second segments at all frequencies (0.0 - 0.25 Hz). The cross-spectra were not smoothed.
- Dispersive signal model oriented to a beam direction of 90°, the approximate azimuth to central Asia.
- Signal-to-noise ratio equal to four at all frequencies, to maintain a balance between signal preservation and noise rejection.
- Two percent white noise added to the data to stabilize filter design.

TABLE IV-1

NOISE SAMPLE DATA USED TO ESTIMATE ARRAY PROCESSING PERFORMANCE

(This list is only part of the noise samples used for the noise study in this report.)

Noise Sample Specification	Date	Start Time	Segments* Edited	Segments* used in MCF Design	
				Start	End
NOIS*005*13A	01/05/72	13:00:00	85	43	85
NOIS*005*19A	01/19/72	19:00:00	78	30	67
NOIS*012*21A	01/12/72	21:30:00	85	21	53
NOIS*013*03A	01/13/72	03:30:00	70	30	62
NOIS*013*08A	01/13/72	08:30:00	71	35	70
NOIS*019*04A	01/19/72	04:30:00	85	14	67
NOIS*019*10A	01/19/72	10:30:00	71	23	62
NOIS*030*23A	01/30/72	23:15:00	98	52	95
NOIS*041*18A	02/10/72	18:00:00	86	15	65
NOIS*057*07A	02/26/72	07:30:00	100	37	69
NOIS*068*22A	03/08/72	22:00:00	100	50	90

* 1 segment is 256 seconds long

The frequency domain filter coefficients were transformed to time domain operators and subsequently were convolved with time data to obtain a MCF output. The MCF and BS processors were applied to two sections (each about 3000 seconds long) of each noise sample. The first section, within the MCF design gate, was called the "on-design" portion; the second section, outside of the MCF design gate but within the same noise sample, produced the "off-design" protion. Table IV-2 gives a list of the sites used (see also Figure II-1 in Section II of this report).

Bandpass filters then were applied to the beams and the RMS values were calculated. The passbands were 0.025 - 0.050 Hz, 0.025 - 0.059 Hz, and 0.020 - 0.10 Hz. The first passband has been used for general noise analysis and was used here for comparison; the second passband is normally used for event processing at NORSAR; the third passband covers the central portion of the NORSAR long-period seismometer response.

The noise reduction, i.e., array gain, achieved by each processor was computed as the ratio of average single site RMS amplitude to the RMS amplitude of the beam. The MCF over BS noise reduction is listed in Table IV-3 for various array configurations. Within the on-design portion of the data, the MCF was always superior to the beamsteer. This superiority of the MCF was generally maintained with data in the off-design gate, although improvements were smaller. The broadest band (0.02 - 0.10 Hz) MCF had the best noise reduction and the narrowest band (0.025 - 0.050 Hz) MCF showed the poorest. This is expected because the coherent energy is concentrated between 0.05 and 0.10 Hz.

The correlation between the noise level and the MCF over BS noise reduction is worth noting. Using the full array results (Table IV-3), the average single site RMS noise values, the beamsteer levels for off-design

TABLE IV-2 (page 1 of 2)

LIST OF SITES USED FOR ARRAY PROCESSING EVALUATION

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
NOI*005*13A	Full Array	X		X	X	X			X		X		X	X	X		X	X			X		
	Outer Ring	X								X	X		X	X	X		X	X			X		
	Inner Ring	X		X	X	X			X														
	Special	X		X	X	X							X	X	X								
NOI*005*19A	Full Array	X		X	X	X	X	X						X	X		X	X			X		
	Outer Ring	X												X	X		X	X			X	X	X
	Inner Ring	X		X	X	X	X	X															
	Special	X				X	X	X							X		X	X					
NOI*012*21A	Full Array	X		X	X	X	X	X	X		X	X		X	X		X	X	X				
	Outer Ring	X									X	X		X	X		X	X	X				
	Inner Ring	X		X	X	X	X	X	X														
	Special	X				X	X	X									X	X	X				
NOI*013*03A	Full Array	X		X	X	X	X	X	X		X	X		X	X		X	X	X		X		
	Outer Ring	X									X	X		X	X		X	X	X		X		
	Inner Ring	X		X	X	X	X	X	X														
	Special	X		X	X	X								X	X								
NOI*013*08A	Full Array	X			X	X	X		X					X	X	X	X	X	X		X	X	
	Outer Ring	X												X	X		X	X	X		X	X	
	Inner Ring	X			X	X	X		X														
	Special	X			X	X	X		X						X		X						
NOI*019*04A	Full Array	X			X	X	X	X	X		X	X			X	X	X	X	X			X	
	Outer Ring	X									X	X			X	X	X	X	X			X	
	Inner Ring	X			X	X	X	X	X														
	Special	X			X	X	X								X	X	X						

TABLE IV-2 (page 2 of 2)

LIST OF SITES USED FOR ARRAY PROCESSING EVALUATION

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
NOI*019*10A	Full Array	X			X	X	X	X			X	X			X		X	X	X			X	
	Outer Ring	X									X	X			X		X	X	X			X	
	Inner Ring	X			X	X	X	X															
	Special	X			X	X	X	X							X		X						
NOI*030*23A	Full Array	X		X	X		X	X	X		X			X	X	X	X	X		X	X	X	
	Outer Ring	X									X			X	X	X	X	X		X	X	X	
	Inner Ring	X		X	X		X	X	X														
	Special	X		X	X		X	X	X						X								
NOI*041*18A	Full Array			X	X	X	X	X	X		X			X			X	X		X	X	X	X
	Outer Ring										X			X			X	X		X	X	X	X
	Inner Ring			X	X	X	X	X	X														
	Special			X	X	X	X	X	X								X						
NOI*057*07A	Full Array	X		X	X	X	X	X	X		X			X	X					X	X	X	X
	Outer Ring	X									X			X	X					X	X	X	X
	Inner Ring	X		X	X	X	X	X	X														
	Special	X						X	X											X	X	X	X
NOI*068*22A	Full Array			X	X	X	X	X	X				X	X		X	X	X	X	X	X	X	X
	Outer Ring												X	X		X	X	X	X	X	X	X	X
	Inner Ring			X	X	X	X	X	X														
	Special					X	X	X									X	X	X	X			

TABLE IV-3

IMPROVEMENTS (dB) IN NOISE REDUCTION
OF MCF OVER BS PROCESSOR
(PAGE 1 OF 2)

Noise Sample	Site Configuration	Number of Sites	MCF over BS Noise Reduction (in dB)					
			On-Design			Off-Design		
			0.025 to 0.050 Hz	0.025 to 0.059 Hz	0.020 to 0.10 Hz	0.025 to 0.050 Hz	0.025 to 0.059 Hz	0.020 to 0.10 Hz
NOIS *005 *13A	Full Array	12	1.8	3.5	7.2	1.0	0.7	1.2
	Outer Ring	9	2.9	2.9	5.9	2.8	4.2	6.1
	Inner Ring	5	2.2	3.5	5.5	1.5	(-0.3)	0.2
	Special Subarray	7	2.3	2.7	7.5	2.4	2.1	(-1.2)
NOIS *005 *19A	Full Array	11	5.1	3.5	6.6	3.1	2.3	8.5
	Outer Ring	8	3.5	6.0	4.4	2.9	3.9	4.6
	Inner Ring	6	7.5	6.5	6.1	7.4	5.6	4.3
	Special Subarray	7	4.0	4.2	6.4	6.0	6.4	6.3
NOIS *012 *21A	Full Array	14	3.0	4.3	7.6	0.2	0.7	2.7
	Outer Ring	8	4.1	4.7	6.3	1.2	2.0	4.1
	Inner Ring	7	3.8	5.0	5.8	0.6	1.2	2.3
	Special Subarray	7	4.5	5.0	5.8	0.6	0.5	2.1
NOIS *013 *03A	Full Array	15	2.6	3.0	4.0	0.0	0.5	3.3
	Outer Ring	9	2.3	2.9	3.7	0.2	1.4	3.7
	Inner Ring	7	2.1	2.3	3.1	0.6	0.7	2.7
	Special Subarray	6	3.8	3.3	4.5	(-0.1)	(-0.1)	5.0
NOIS *013 *08A	Full Array	13	8.1	7.8	8.4	6.2	5.9	6.5
	Outer Ring	8	3.5	4.5	5.0	3.1	3.3	4.0
	Inner Ring	5	2.1	3.8	4.3	2.4	3.9	4.0
	Special Subarray	7	2.6	3.1	5.4	1.3	2.5	5.3

TABLE IV-3

IMPROVEMENTS (dB) IN NOISE REDUCTION
OF MCF OVER BS PROCESSOR
(PAGE 2 OF 2)

Noise Sample	Site Configuration	Number of Sites	MCF over BS Noise Reduction (in dB) On-Design 0.025 to 0.050 Hz	On-Design 0.025 to 0.059 Hz	On-Design 0.020 to 0.10 Hz	Off-Design 0.025 to 0.050 Hz	Off-Design 0.025 to 0.059 Hz	Off-Design 0.020 to 0.10 Hz
NOIS	Full Array	13	1.6	5.0	6.9	(-1.1)	0.8	2.9
*019	Outer Ring	9	2.1	4.3	5.9	0.3	1.5	6.4
*04A	Inner Ring	6	1.5	3.4	5.5	1.2	1.2	3.1
	Special Subarray	7	2.5	2.8	5.9	0.8	0.8	3.4
NOIS	Full Array	12	3.1	6.6	8.4	0.9	3.2	5.0
*019	Outer Ring	8	3.6	6.0	6.5	1.3	4.1	4.5
*10A	Inner Ring	5	1.8	3.2	6.3	1.7	1.6	4.5
	Special Subarray	7	1.2	2.5	6.6	0.6	1.0	4.2
NOIS	Full Array	15	2.5	6.1	10.3	2.4	3.1	8.2
*030	Outer Ring	10	2.5	5.2	8.1	2.2	3.6	5.8
*23A	Inner Ring	6	3.9	7.0	9.8	3.0	5.4	7.8
	Special Subarray	7	3.1	5.6	8.6	2.6	4.0	8.2
NOIS	Full Array	14	3.6	6.0	8.5	2.4	4.9	9.0
*041	Outer Ring	8	1.5	3.0	4.2	0.9	2.2	3.5
*18A	Inner Ring	6	5.3	6.7	6.1	5.0	6.6	5.5
	Special Subarray	7	5.4	7.0	7.0	4.6	5.8	6.1
NOIS	Full Array	14	3.6	3.8	5.6	(-1.4)	(-0.4)	2.9
*057	Outer Ring	8	4.6	4.0	5.2	(-1.3)	0.3	3.9
*07A	Inner Ring	7	5.9	4.2	4.4	2.7	2.5	3.6
	Special Subarray	7	6.3	5.9	6.2	2.2	2.0	3.3
NOIS	Full Array	16	1.9	3.1	6.4	0.4	1.8	5.6
*068	Outer Ring	10	3.5	4.0	4.0	0.7	2.8	2.1
*22A	Inner Ring	6	3.8	3.4	5.5	3.9	3.8	4.9
	Special Subarray	7	3.8	3.9	6.5	2.1	2.2	5.9

and on-design noise, and the MCF over BS noise reduction all were plotted versus the noise samples for each of the three passbands (Figures IV-1 to IV-3). For off-design noise, the MCF improvements range from -1 to 6 dB in the 0.025 - 0.050 Hz passband, 0 to 6 dB in the 0.025 - 0.059 Hz passband, and 1 to 8 dB in the 0.02 - 0.10 Hz passband. The on-design improvements were generally better than the off-design improvements, as expected. Surprisingly, the best MCF improvements were not obtained when the noise levels were the highest.

Table IV-4 shows the mean improvements of the MCF over BS processor for several array and subarray configurations. For any given passband the on-design noise always had better improvements than the off-design noise. For both off-design and on-design portions, the results indicate that the inner-ring and the seven-site subarray yielded slightly better MCF over BS improvements than the outer-ring and full array. Also, the Improvements listed are about the same as those observed for last year's data.

C. AZIMUTHAL DEPENDENCE OF ARRAY GAIN

The MCF and BS processor performances would be expected to be strongly dependent on noise field structure relative to the direction of the beam. To examine this aspect the noise sample NOIS*019*10A was analyzed in detail. The high resolution f-k spectrum for this noise sample showed that at 0.050 Hz and 0.059 Hz the noise came from northwest, with a peak at 292°.

The MCF and BS outputs were formed using 12 sites for look directions of 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°. These beams included both on-design and off-design portions of the noise sample. The resulting MCF and BS array gains are shown in Figures IV-4 through IV-9.

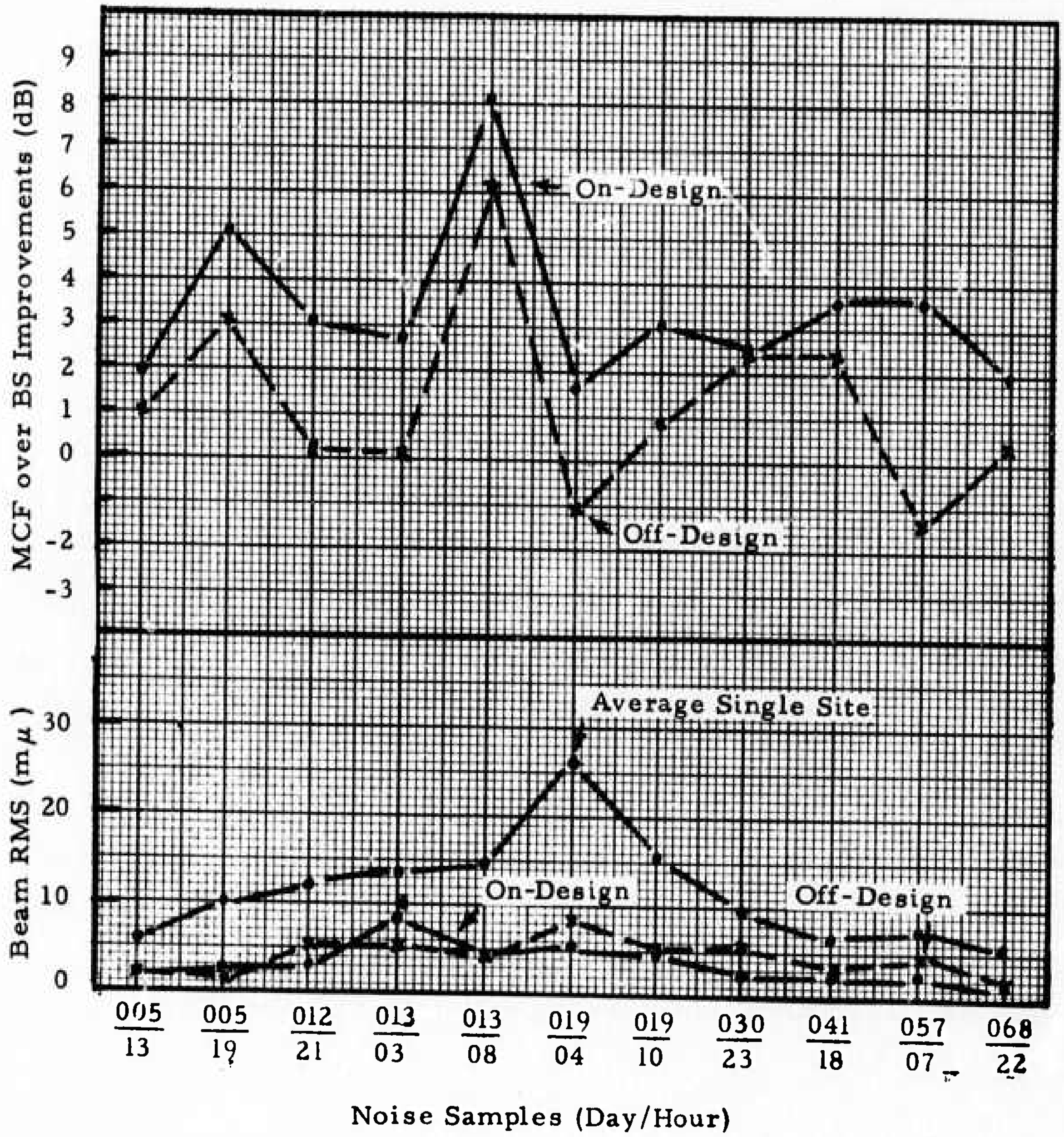


FIGURE IV-1

PROFILES OF ARRAY GAINS
(0.025 -0.050 Hz)

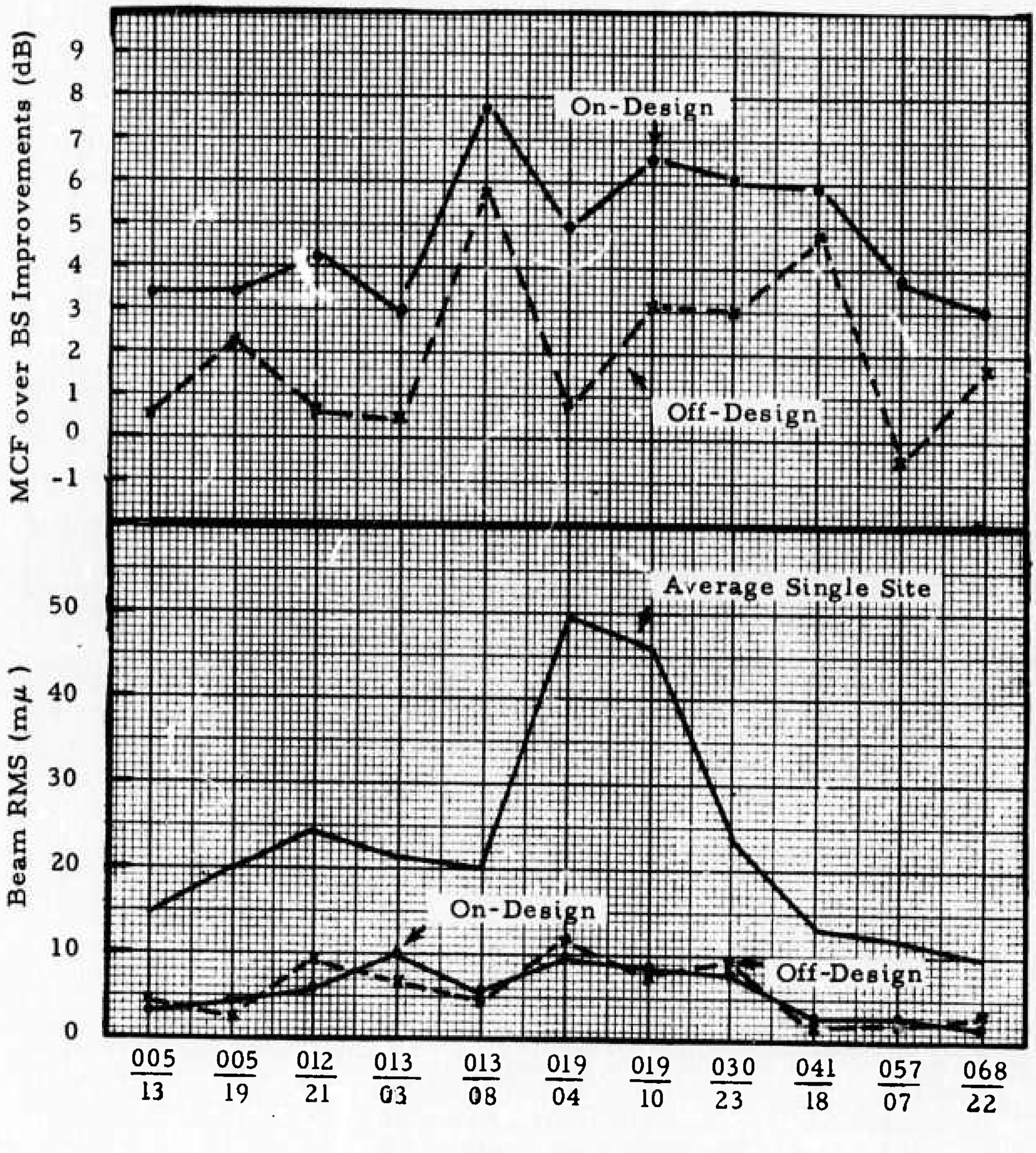


FIGURE IV-2

PROFILES OF ARRAY GAINS
(0.025-0.059 Hz)

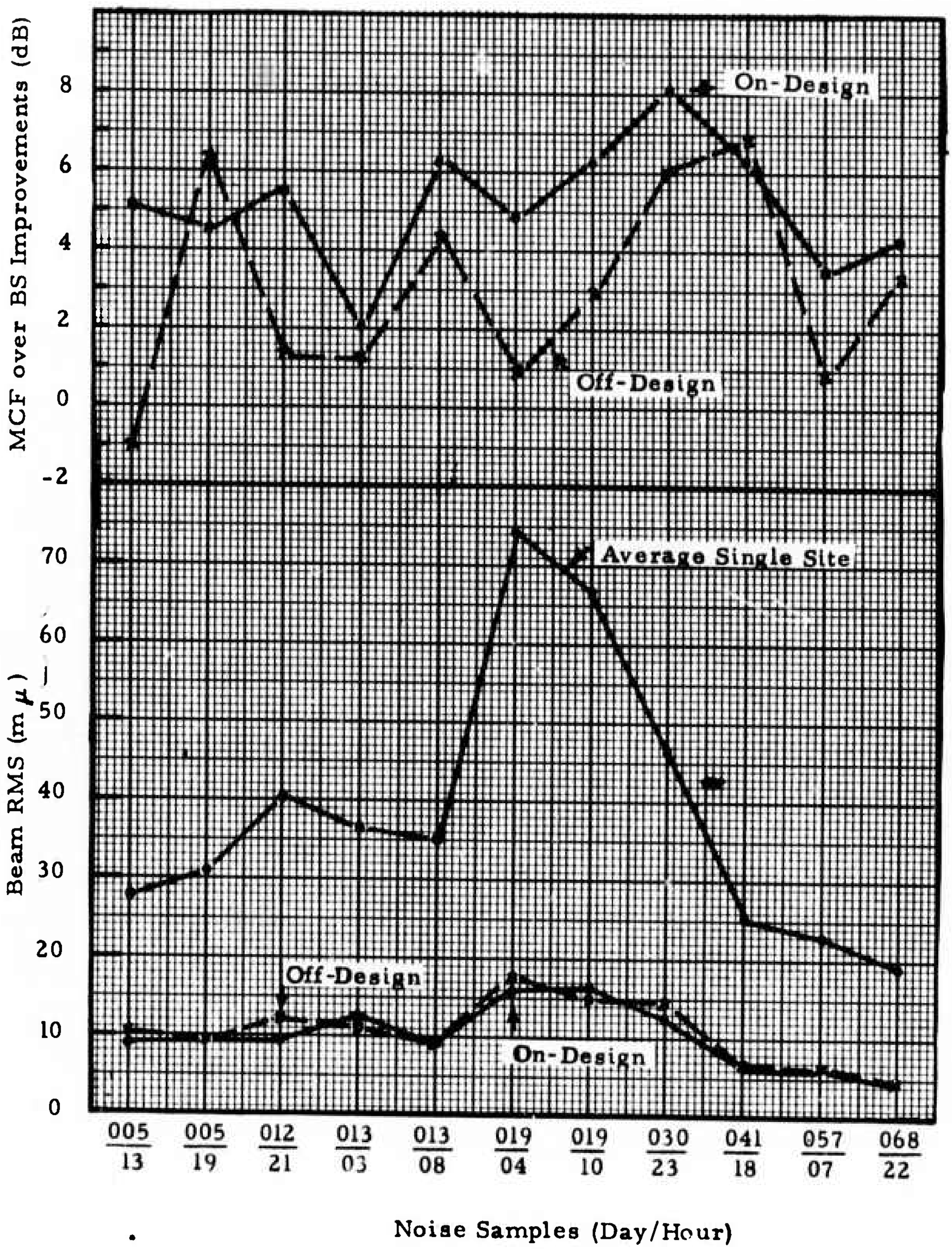


FIGURE IV-3

PROFILES OF ARRAY GAINS
(0.02-0.10 Hz)

TABLE IV-4

MEAN IMPROVEMENTS (dB) IN NOISE REDUCTION
OF MCF OVER BS PROCESSING

Array Structures	Mean Improvements (dB) of MCF over BS Processors for Various Passbands (Hz)					
	On-Design			Off-Design		
	0.025-0.050	0.025-0.059	0.020-0.10	0.025-0.050	0.025-0.059	0.020-0.10
Full Array	3.4	4.8	7.3	1.3	2.1	5.1
Outer Ring	3.1	4.3	5.4	1.3	2.7	4.4
Inner Ring	3.6	4.5	5.7	2.7	2.9	3.9
Special Subarray	3.6	4.2	6.4	2.1	2.5	4.4

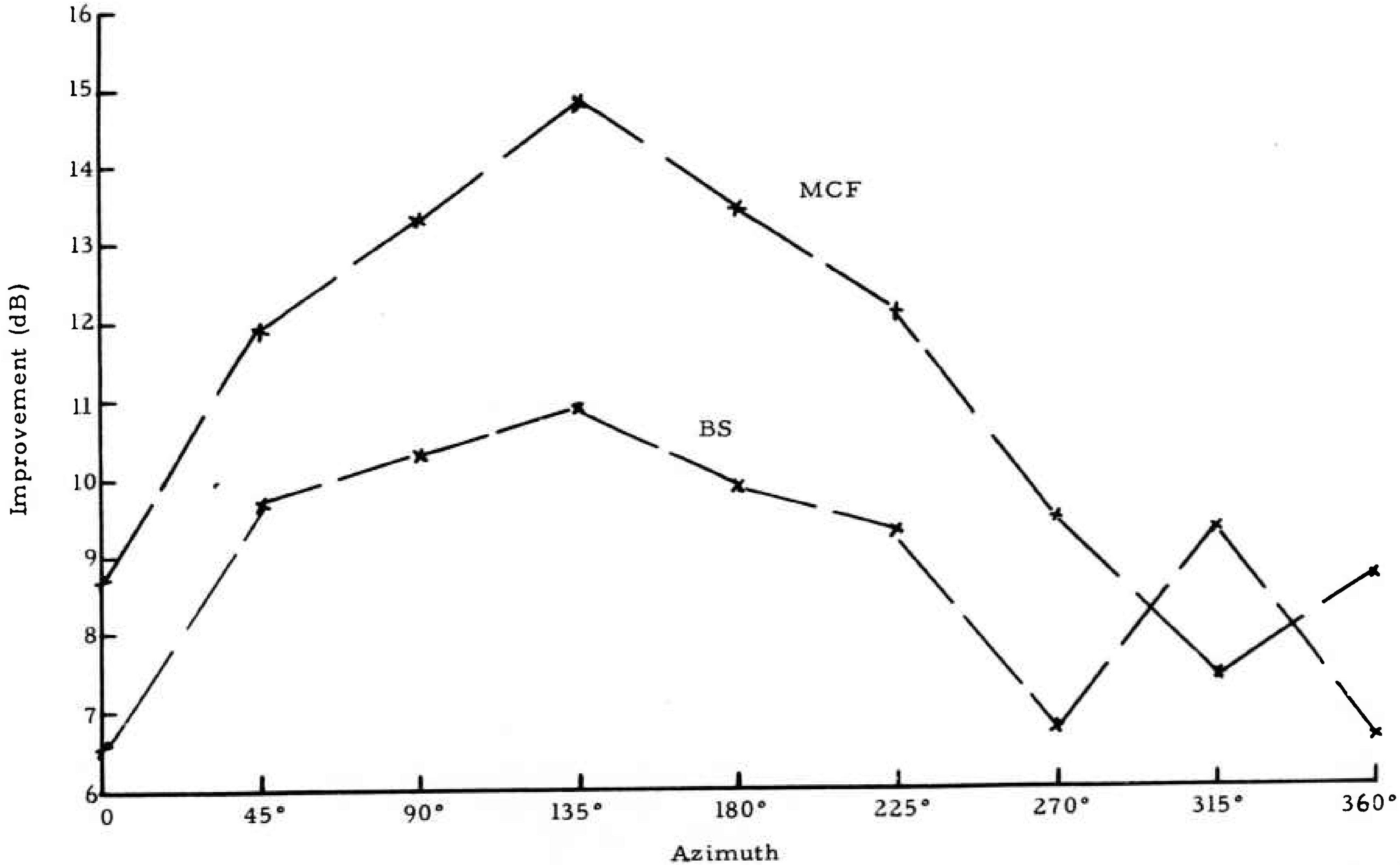


FIGURE IV-4

IMPROVEMENT vs. AZIMUTH FOR MCF AND BS PROCESSORS
0.025-0.050 Hz, On-Design Noise, Day 019, 1972

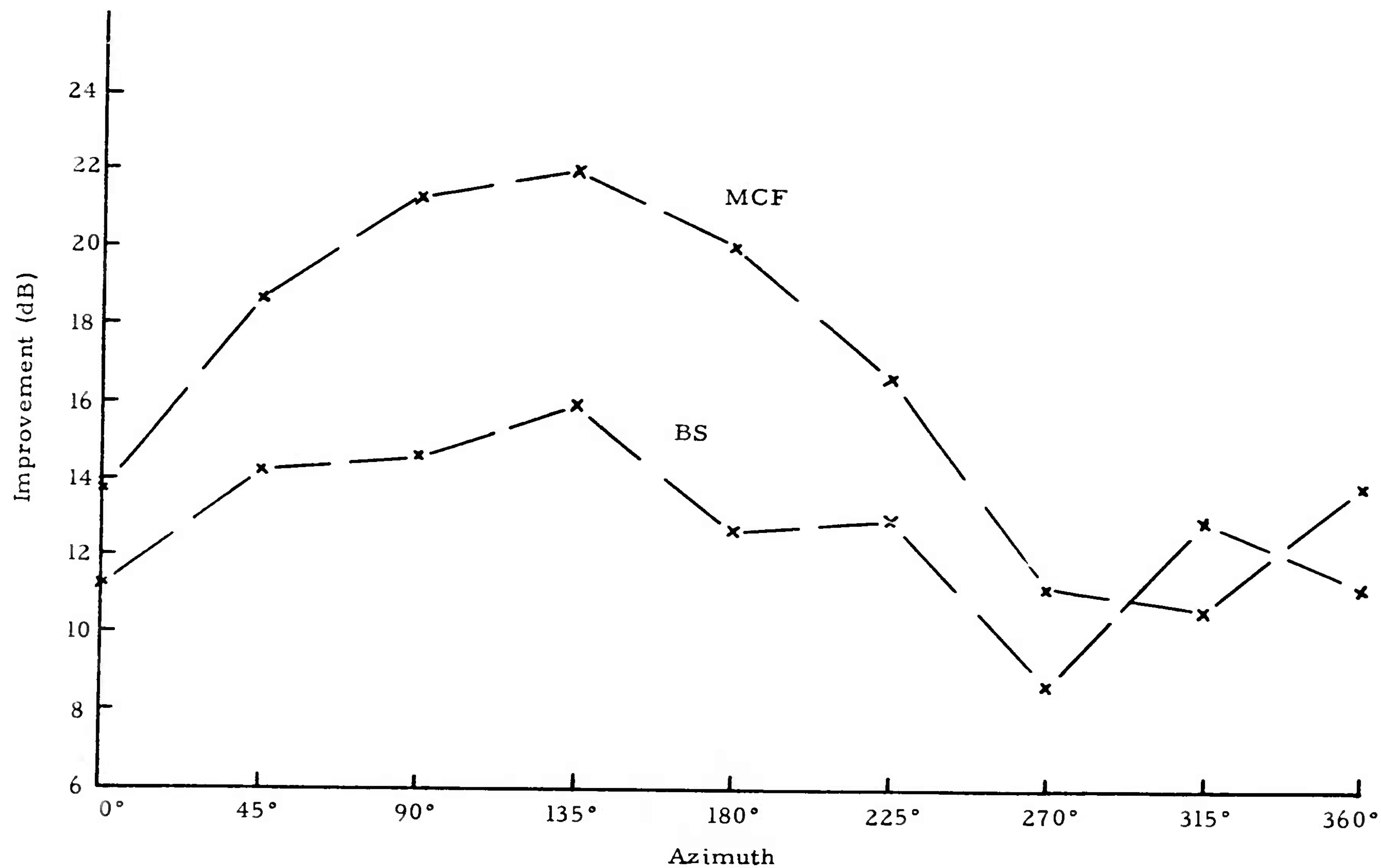


FIGURE IV-5

IMPROVEMENT vs. AZIMUTH FOR MCF AND BS PROCESSORS
0.025-0.059 Hz, On-Design Noise, Day 019, 1972

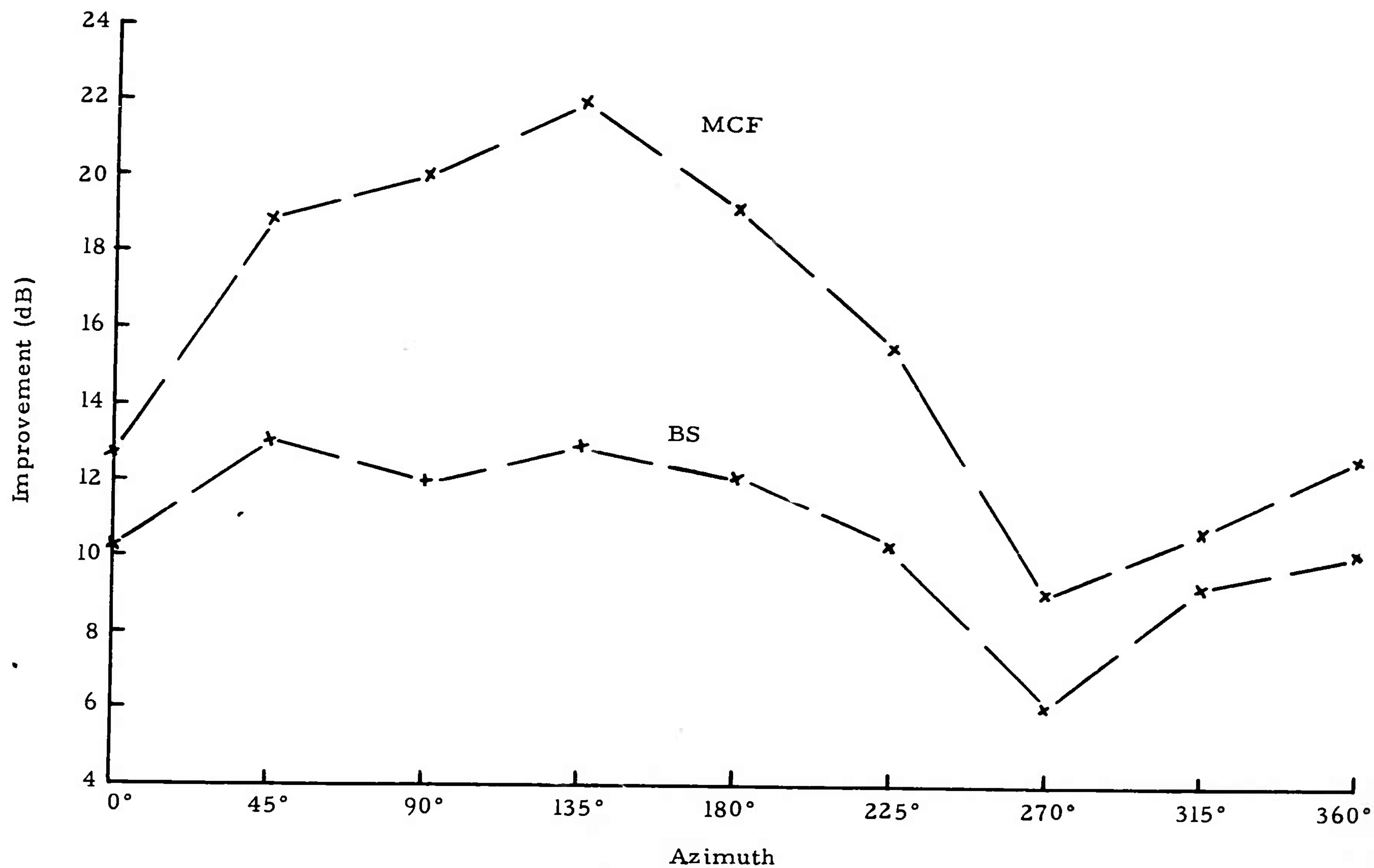


FIGURE IV-6

IMPROVEMENT vs. AZIMUTH FOR MCF AND BS PROCESSORS
0.02-0.10 Hz, On-Design Noise, Day 019, 1972

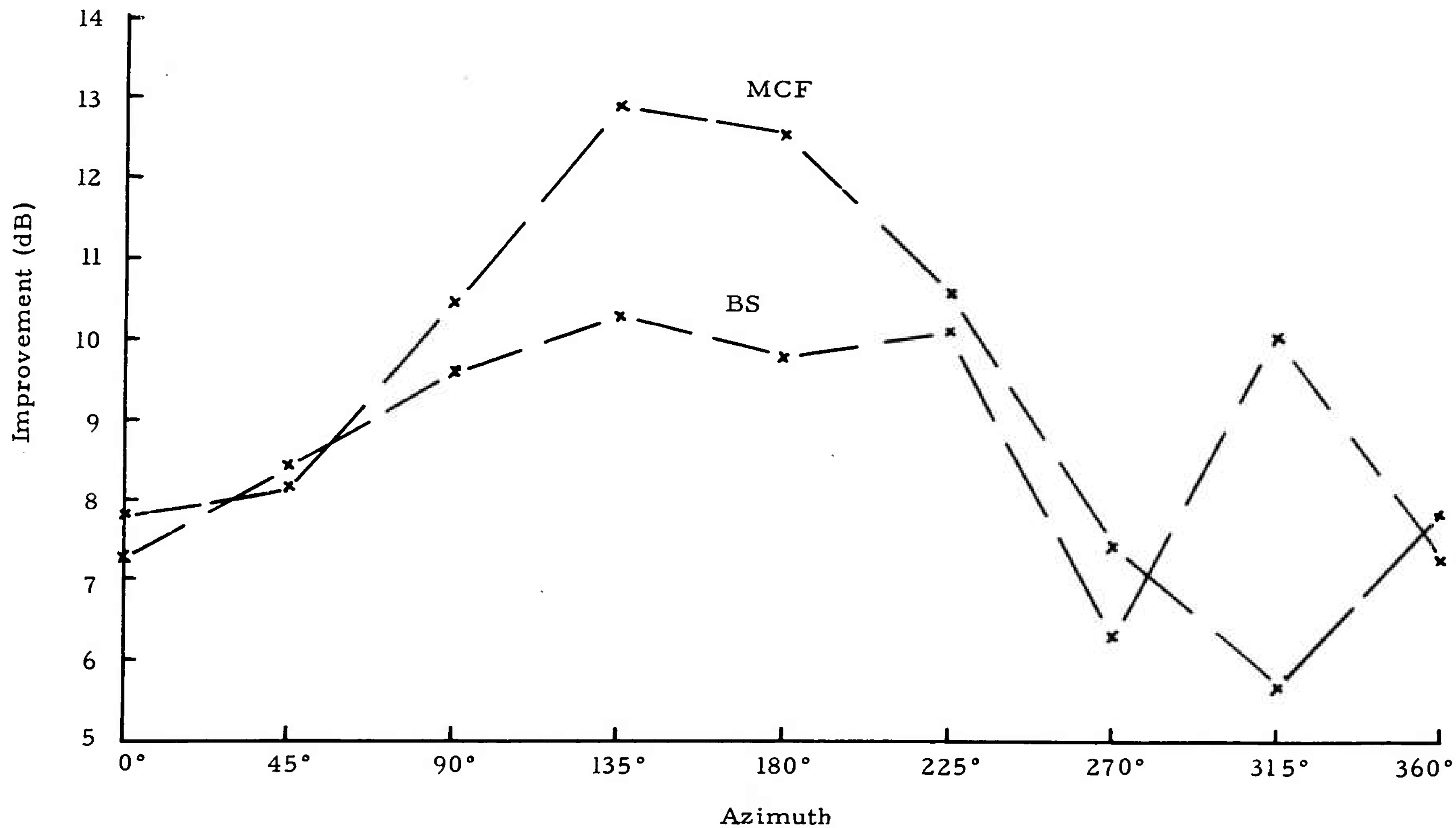


FIGURE IV-7

IMPROVEMENT vs. AZIMUTH FOR MCF AND BS PROCESSORS
0.025-0.050 Hz, Off-Design Noise, Day 019, 1972

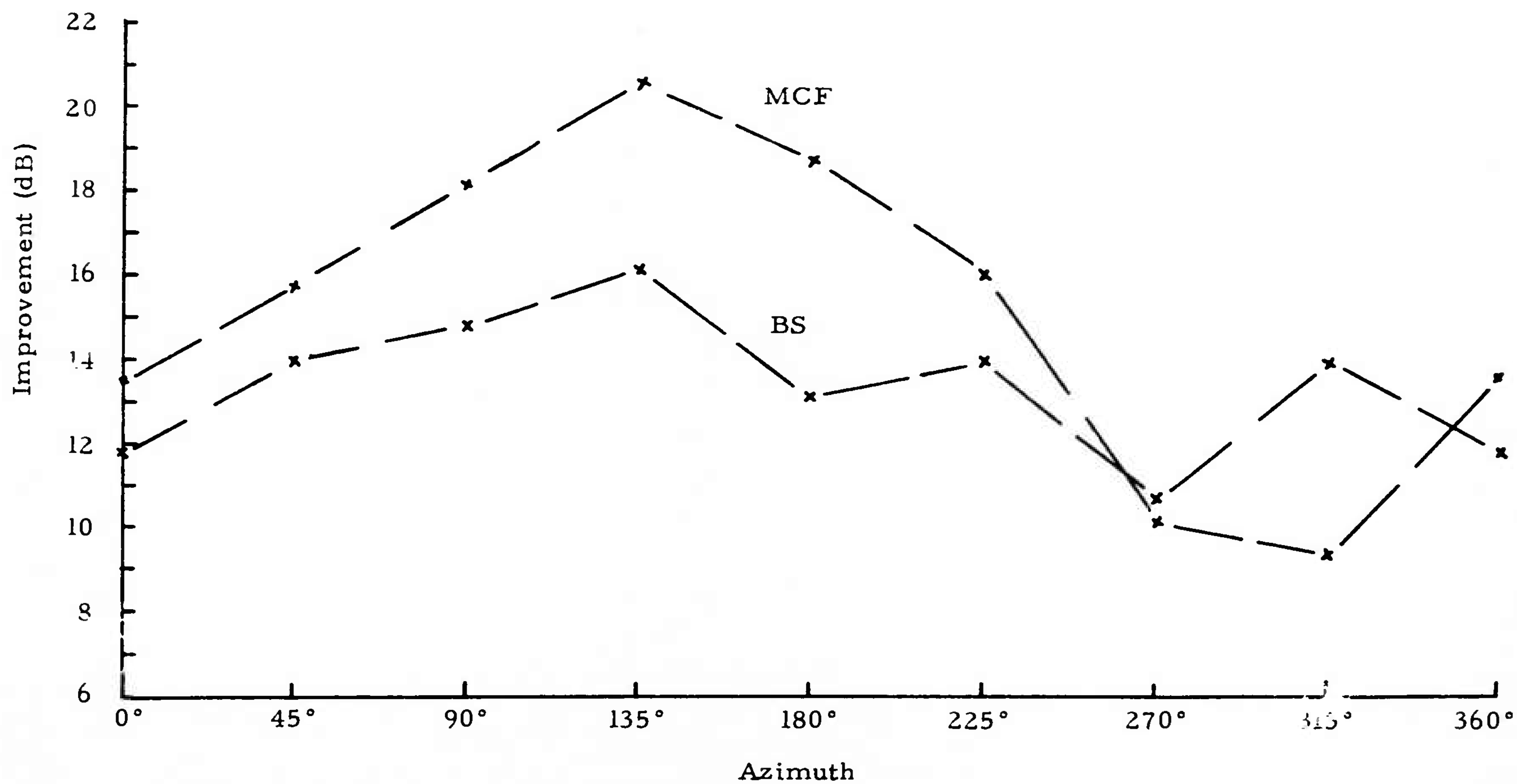


FIGURE IV-8

IMPROVEMENT vs. AZIMUTH FOR MCF AND BS PROCESSORS
0.025-0.059 Hz, Off-Design Noise, Day 019, 1972

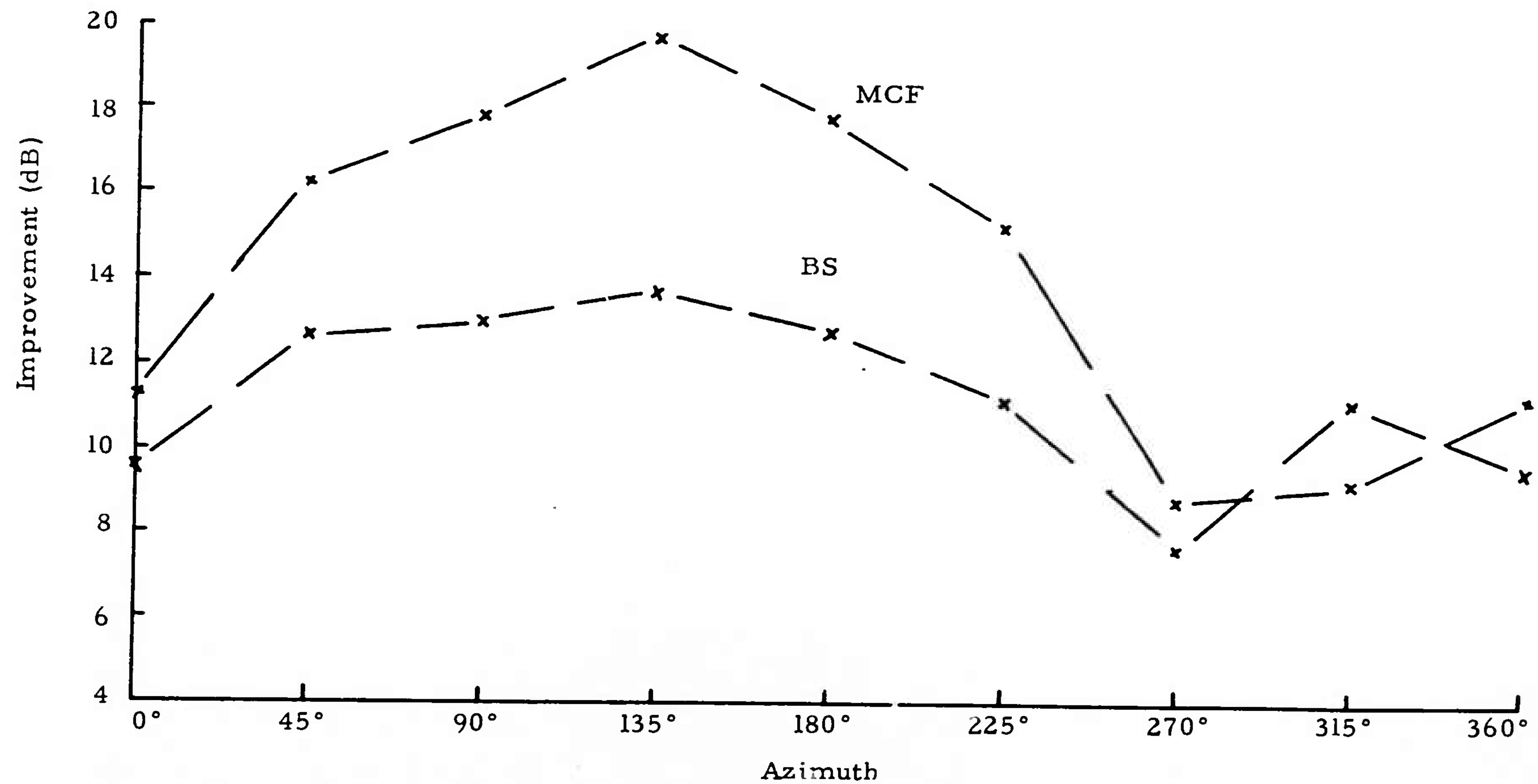


FIGURE IV-9

IMPROVEMENT vs. AZIMUTH FOR MCF AND BS PROCESSORS
0.020-0.10 Hz, Off-Design Noise, Day 019, 1972

From Figure IV-4 to Figure IV-6 (on-design noise results), the MCF had from 2 to 5 dB better noise reduction for azimuth from 0^{o} to 270^{o} and essentially equivalent performance between 270^{o} and 0^{o}. For off-design gains (Figures IV-7 to IV-9), the MCF's still did better than BS processors, but the gains were 0 to 4 dB. Improvements for both MCF and beamsteer processors were smaller between 270^{o} and 360^{o}, which would be expected since that is the sector where most of the propagating energy is coming from.

D. MCF AND BS PROCESSORS APPLIED TO SIGNALS

Selected array processors were also applied to a few signals to compare their performances for practical signal extraction problems. Care was taken to insure that channels used in the design of the MCF also were available for event processing. Time separations between signals and noise samples ranged from 8 hours to 31 hours.

Noise rejection estimates were obtained by computing RMS levels in a 1500-second time gate taken prior to P-wave arrival. Relative signal beamforming loss was estimated by measuring the maximum zero-to-peak values of the signal waveforms. Results are presented in Table IV-5. The MCF signal amplitudes were essentially the same as those of the beamsteer, indicating that signal loss from beamforming was the same for MCF and BS processors. However, somewhat greater noise reductions were achieved by the MCF. The net improvements in SNR achieved by the MCF over the BS ranged from 0 to 6 dB, with an average at about 3 dB. This is on the same order as off-design mean improvements shown in Table IV-4, despite the fact that these noise data generally were further separated in time from the design noise than the samples used in Table IV-4. It appears that MCF processing can, on the average, produce some improvement over BS processing for winter noise provided that a long noise sample is

TABLE IV-5

THE MCF AND BS PROCESSORS APPLIED TO SIGNAL GATE

Events and Noise Sample Used for MCF Design	Number of Sites	Signal-to-Noise Ratio (dB) For Various Passbands			MCF over BS Improvements	Separation of Signal and Noise Sample
		Passbands	MCF	BS	MCF over BS	
TAI*004*12NL NOIS*005*19A	7	0.025-0.05 Hz	36.6	34.8	1.8	31 hrs.
		0.025-0.059Hz	35.8	34.9	0.9	
		0.02 -0.10 Hz	39.7	39.6	0.1	
TAI*006*06NL NOIS*005*19A	7	0.025-0.05 Hz	23.9	21.0	2.9	11 hrs.
		0.025-0.059Hz	26.2	24.2	2.0	
		0.02 -0.10 Hz	23.8	23.4	0.4	
IRA*006*09A NOIS*005*19A	11	0.025-0.05 Hz	34.7	29.9	4.8	14 hrs.
		0.025-0.059Hz	34.2	29.4	4.8	
		0.020-0.10 Hz	32.8	27.2	5.6	
GRE*012*13NL NOIS*012*21A	14	0.025-0.05 Hz	44.3	44.6	(-0.3)	8 hrs.
		0.025-0.059Hz	43.2	39.8	3.4	
		0.020-0.10 Hz	41.6	36.4	5.2	

used in the MCF design and that this noise sample is within about one day of the event to be processed.

E. SUMMARY

The main results from the comparative evaluation of the MCF and BS processor using winter noise are the following:

- MCF's generally achieved better noise rejection than beamsteer filters: 2-8 dB for on-design noise and 0~6 dB for off-design noise in the 0.025 - 0.059 Hz signal processing band.

- The MCF outperformed the beamsteer processor by 2~5 dB for on-design noise and by 0~4 dB for off-design noise for look directions significantly different from the predominant noise azimuths. Serious deterioration in array gains for both the MCF and beamsteer was seen at azimuths spanning predominant noise azimuths.

- The MCF gave 0~6 dB, and typically 3 dB more SNR improvement than the BS for example of "practical" signal extraction (usually real signals), suggesting that with the aid of MCF processing the winter detection threshold at NORSAR could be decreased by on the order of 0.15 M_s units.

SECTION V
MATCHED FILTERING PERFORMANCE

A. INTRODUCTION

Matched filters were applied to the beams formed for the events processed this year to measure the improvement in signal-to-noise ratio (SNR) which could be obtained at NORSAR. The objectives of measuring the effectiveness of matched filters were:

- To determine the available SNR gain from matched filters.
- To examine the variation in these gains by region and surface wave mode.
- To determine if seismic regions could be catagorized by matched filter parameters.

These objectives were reached with good success. In particular, we were highly successful in our first attempt to define seismic regions on the basis of a matched filter parameter.

Chirp filters were routinely applied to the three-component beams formed for each event processed this year. In contrast to last year's work, reference waveform filters*(RWF) were not applied routinely to all events from the areas of central Italy, eastern Kazakh, and a small area east of Kamchatka. The reasons for this were that:

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* In the report on last year's work, reference waveform filters were called "master" waveform filters.

- RWF's generally did not show a clear-cut superiority to chirp filters in signal-to-noise (SNR) improvement.

- The event source parameters, which control the effectiveness of a RWF, were unknown; thus there was no *a priori* means of selecting a RWF which would produce good SNR improvement.

- The relative importance of the source parameters and their degree of interaction also were unknown; hence they could not be used to categorize event behavior on a regional basis.

The size of the combined data base this year allowed a sufficiently dense sampling of events in some areas so that distinct patterns of behavior from region to region could be ascertained. These patterns were primarily due to similarities in chirp filter length and SNR improvements and permitted tentative identification of regional boundaries. The events in each region were analyzed in terms of SNR improvement.

B. DESCRIPTION OF METHOD

The SNR improvement of the matched filter was computed by applying in turn the matched filter and a bandpass filter to the signal waveform and to a section of noise preceding the signal. The SNR of the output of each filter was then computed on the ratio of zero-to-peak signal amplitude to RMS noise. The ratio, in dB, of the matched filter SNR to the bandpass filter SNR is the SNR improvement. The signal gate generally included all major signal energy; the noise gate was generally 1000 seconds long and was chosen to exclude any obvious signal energy from other events.

The number describing peak signal amplitude more correctly describes peak signal-plus-noise amplitude, particularly for weak signals. For this reason, we shall henceforth refer to the signal-plus-noise-to-noise ratio (SNNR) instead of signal-to-noise ratio.

The filters were designed in the frequency domain by specifying the passband of the bandpass filter and the passband and length* of the chirp. The responses were not tapered at the band edges. The passband of the bandpass, RWF, and chirp filters used for signal processing at NORSAR this year was 0.025-0.059 Hz, or 17-40 seconds. The chirps were linear in the sense that the phase rate of change, i.e., frequency, was a linear function of time.

The beams to which these filters were applied were formed using a phase velocity of 3.5 km/sec for the vertical and radical components and 4.0 km/sec for the transverse component.

Five chirp filters and one bandpass filter were applied sequentially to each component beam. Trial chirp lengths were chosen to cover a moderate range about the predicted best length, which was obtained either from group velocity curves or from previous processing experience. The chirp filter length which produced the maximum signal peak was considered to be the "best" length.

C. REGIONALIZATION OF EVENTS BY CHIRP FILTER LENGTH

Experience with signals recorded at ALPA indicates that the optimum length of constant bandwidth chirp filters is linearly proportional to epicentral distance (Harley, 1971, Heiting et al 1972). It has been found that at NORSAR such a simple relationship between length and distance does not exist. Initial estimates of good chirp lengths for events from several areas not covered last year, e.g., Italy, Greece, Iran, and Taiwan, often were quite wrong, necessitating reprocessing in these cases. To increase processing efficiency, a table of chirp lenghts by region was built up empirically and refered to as needed. As the number of processed events increased, the

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* Details of the chirp filter derivation are outlined in Special Report No. 5.

table became rather extensive because some regions required several "best" lengths. Thus, when a sufficient number of events had been processed, maps were produced showing the value of the "best" chirp length in each area. These maps are shown in Figure V-1 and V-2 for the Love wave and Rayleigh wave chirps respectively. The variations of chirp length show distinct regional patterns which, as will be discussed later, were the primary basis for combining events into groups of similar behavior.

The procedure for drawing these maps was as follows. The optimum chirp length for each detected event from the 1971 and 1972 data was plotted at the epicenter location.* Contours were plotted to show lines of constant chirp length. The contouring followed three rules:

- Chirp length should monotonically increase with distance along any great circle path away from NORSAR.
- The data were smoothed as to produce contours which showed primary features rather than each point-to-point variation.
- Contours which were considered relatively reliable were plotted as solid lines. Contours based on only a few widely scattered events and which were considered less reliable were plotted as dashed lines.

In general, the maps for Love and Rayleigh waves are similar, as would be expected. The data for the Rayleigh wave were much less consistent than the Love wave data, however, and hence were more difficult to contour. For Love waves, there seemed to be very few chirp lengths which were greatly different from those of nearby events, while the best chirps for Rayleigh waves often had lengths significantly different. In the one area of the Caspian Sea and its environs, chirp lengths could not be reconciled with the monotonicity

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* Chirp lengths from the 1971 events were scaled to correspond to the slight change in processing passbands.

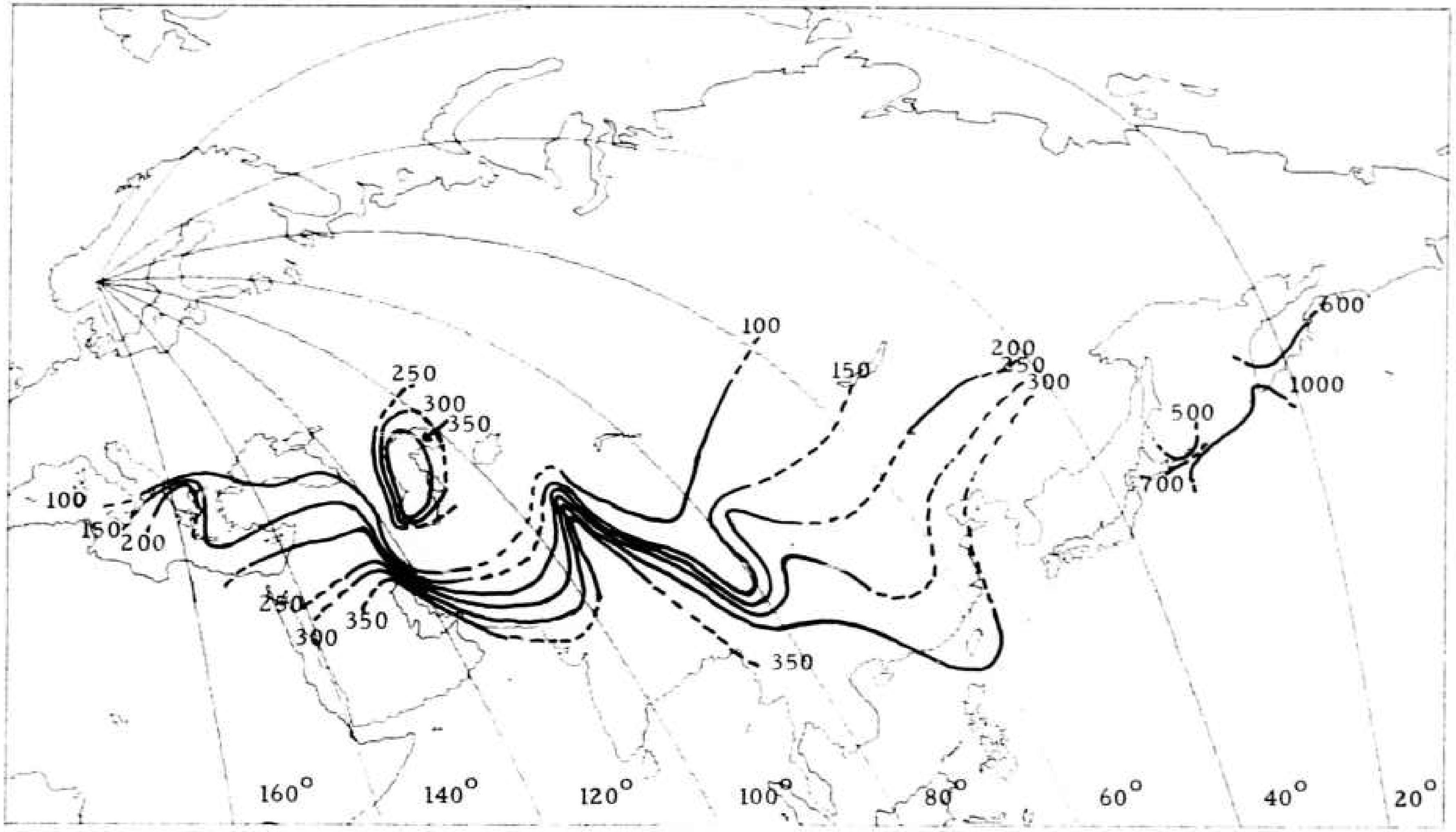

FIGURE V-1

OPTIMUM CHIRP FILTER LENGTHS (IN SECONDS) FOR LOVE WAVES
AT NORSAR FOR THE PASSBAND 0.025 - 0.059 Hz

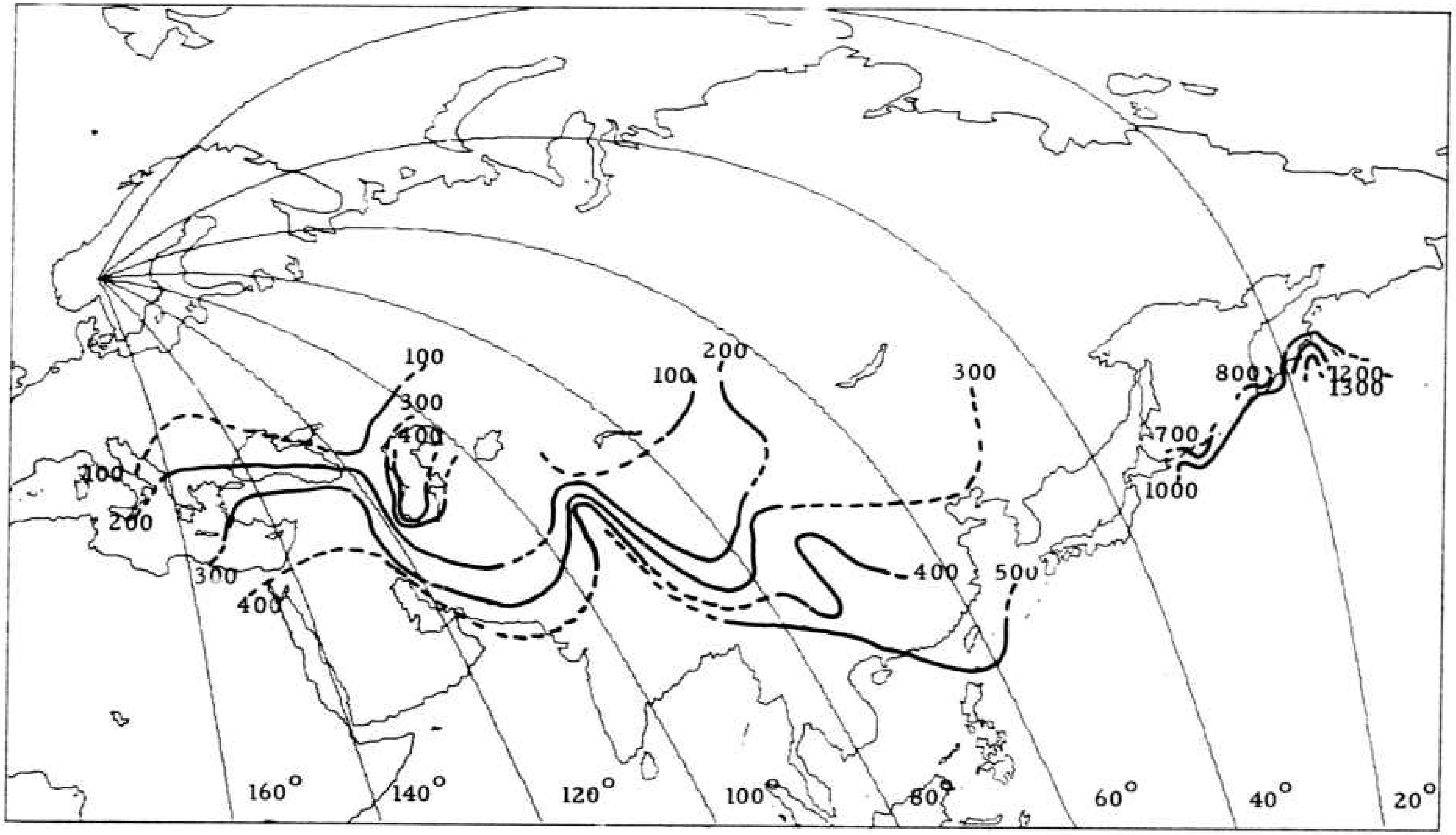

FIGURE V-2

OPTIMUM CHIRP FILTER LENGTHS (IN SECONDS) FOR RAYLEIGH WAVES AT NORSAR FOR THE PASSBAND 0.025 - 0.059 Hz

rule. Events from that region consistently required longer chirp durations than other events surrounding it but slightly further away.

It must be stressed at this point that these maps are not necessarily unique. They are highly useful, however, for predicting what chirp length is needed for an event from some particular location when using the 0.025-0.059 Hz passband. They are not unique for the following reasons:

- the linear group velocity versus frequency chirp only grossly approximates the dispersive characteristics of most events.
- the apparent "best" chirp length is strongly dependent on the source energy spectrum.
- the "best" length is generally a nonlinear function of the passband frequencies.

The events used to compute the SNNR improvements of chirp filters were grouped into 13 regions whose boundaries were suggested by the behavior of the chirp length contours. These regions are shown in Figure V-3 and are identified by a three letter region descriptor.

D. CHIRP FILTER SNNR IMPROVEMENT

Chirp filter SNNR gains were computed using 187 events from 1972 and 45 events from 1971. As mentioned previously, the 1971 and 1972 processing bands were slightly different, but it was felt that the SNNR improvements would not be significantly changed.

The chirp filter SNNR improvements are presented by region in Table V-1. Included in the table are the lengths of the best chirp, the signal-to-noise ratio of the event signal on the bandpassed beam, the SNNR improvements (in dB) and the mean and standard deviation of the improvements. Each component was treated independently. A non-detection is indicated by a dash. Gains were not computed from all event-component detections. First, if none

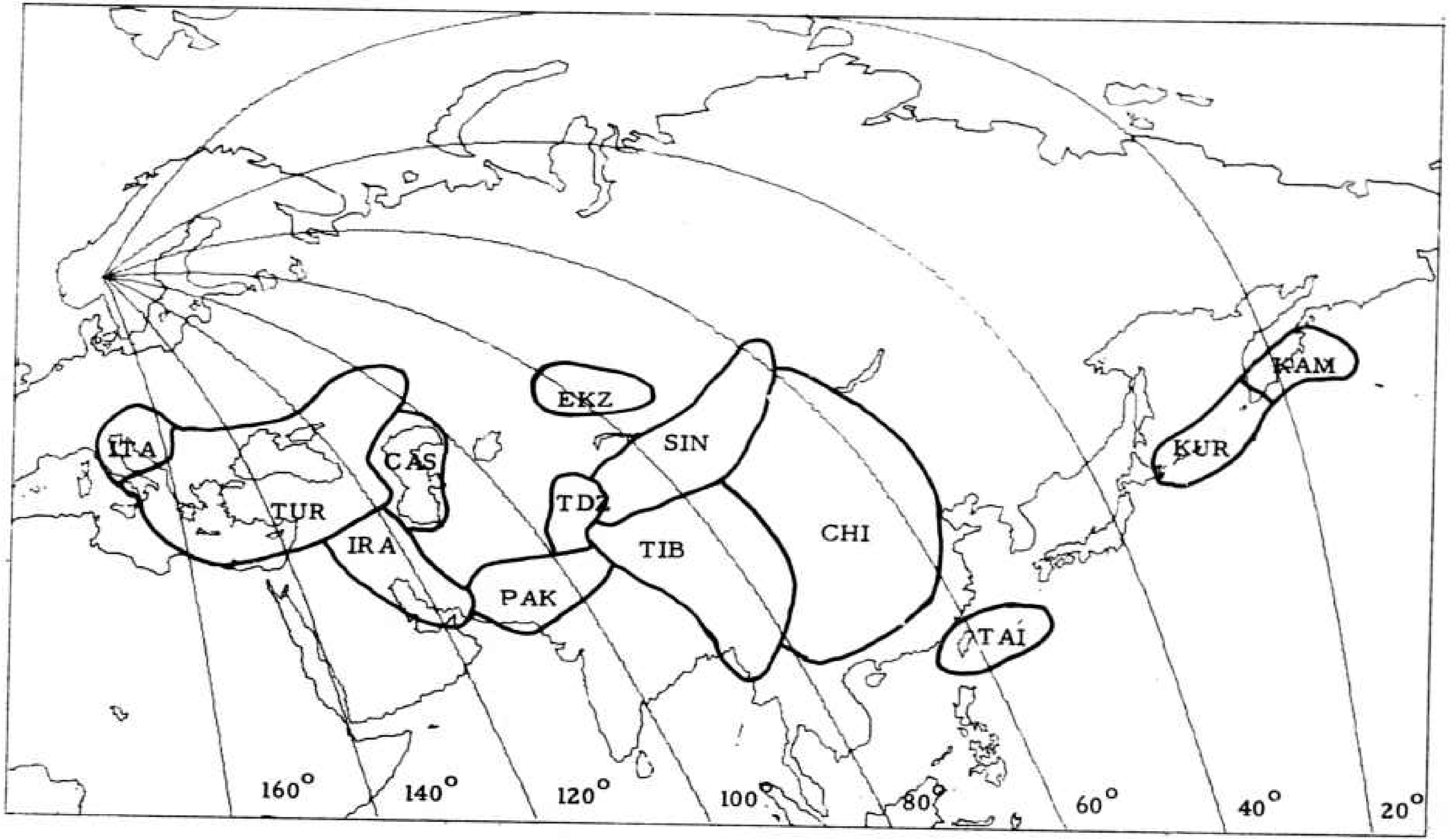

FIGURE V-3

SEISMIC REGIONS DERIVED FROM
CHIRP FILTER ANALYSIS

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

REGION 'ITA' - CENTRAL ITALY, AUSTRIA, NORTHERN YUGOSLAVIA

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
AUS*005*04	80	100	100	16.3	11.7	8.9	0.1	3.7	2.6
AUS*169*09	70	120	120	12.3	30.4	14.6	1.3	3.2	2.9
ITA*035*02	65	85	85	224.4	62.7	53.3	1.9	1.1	-.3
ITA*035*04	65	-	-	3.8*	-	-	0.4	-	-
ITA*035*09	75	65	65	131.3	31.4	24.5	0.3	0.6	0.3
ITA*035*17	75	65	105	114.6	29.5	25.7	0.3	0.8	-.4
ITA*035*19	75	65	65	25.9	8.5	4.4*	1.4	0.3	0.0
ITA*036*05	65	95	95	22.8	12.5	10.7	0.8	-.6	-.3
ITA*036*07	55	105	105	38.4	23.3	19.8	0.9	0.2	-.2
ITA*036*15	75	95	85	98.3	34.8	34.6	2.0	0.2	-1.2
ITA*037*01	65	65	65	88.0	22.1	24.1	1.7	0.3	-.1
ITA*037*21	90	-	-	12.7	-	-	1.9	-	-
ITA*039*12	75	105	105	23.9	10.4	10.4	1.3	-.6	0.3
ITA*166*18	65	110*	110*	847.7	469.4	381.9	1.2	2.8	2.6
ITA*166*21	65	110	110	89.1	28.7	16.0	1.5	0.1	-.3
YUG*177*04	80	160	160	6.3	15.8	7.3	0.9	3.3	3.9
YUG*180*01	80	175	150	42.7	11.9	9.8	1.5	3.0	1.8

MEAN SNNR IMPROVEMENT =	1.19	1.11	0.69
STANDARD DEVIATION =	0.59	1.52	1.56
NUMBER OF EVENTS =	16	14	13

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

REGION 'TUR' - GREECE,TURKEY,BLACK SEA,E EUROPE,E MEDITERRANEAN

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LOT	LRV	LRR	LOT	LRV	LRR	LOT	LRV	LRR
BLS/263/06	130	217	217	0.0	0.0	0.0	1.3	3.8	3.3
BLS/263/10	383	235	235	0.0	0.0	0.0	3.2	3.0	1.9
CAU/283/09	87	87	87	0.0	0.0	0.0	1.0	0.9	0.3
TRS/251/22	108	217	217	0.0	0.0	0.0	2.6	2.6	2.6
TUR/126/04	122	348	348	0.0	0.0	0.0	3.2	5.3	4.2
TUR/143/01	108	305	305	0.0	0.0	0.0	2.5	6.5	6.4
TUR/161/09	139	283	283	0.0	0.0	0.0	4.8	5.6	4.9
BUL*068*22	300	450*	450*	12.6	32.1	14.0	4.4	3.6	2.9
CAU*079*03	100	-	100	16.6	-	5.2*	-1.5	-	1.3
CAU*208*18	60	160	200	21.1	26.1	13.2	0.4	1.8	2.0
CRE*017*05	100	400	400	6.4	5.1*	4.3*	1.3	2.7	2.9
CRE*026*12	-	250	-	-	2.3*	-	-	-2.1	-
CRE*161*07	160	250	250	179.0	161.4	110.7	0.5	3.8	2.7
DOD*020*02	100	300	300	26.8	64.0	55.5	1.3	3.1	3.9
GRE*002*09	150	280	280	4.7*	4.1*	4.8*	2.0	2.6	0.5
GRE*012*13	250	300	-	67.5	126.2	-	2.7	4.1	-
GRE*033*21	220	280	280	42.8	26.0	10.4	1.4	2.0	2.2
GRE*044*13	150	240	240	43.8	15.4	11.3	1.6	-.8	0.7
GRE*047*00	150	280	240	51.8	11.0	12.5	2.1	-.8	0.2
GRE*157*10	100	280	320	138.1	69.2	70.5	-.2	2.3	2.3
GRE*167*00	180	320	280	614.1	562.9	403.1	3.1	5.8	5.3
GRE*190*05	100*	240	240	11.7	12.8	9.5	0.7	4.2	5.5
GRE*200*13	140	160	-	21.9	15.1	-	3.3	1.7	-
MED*191*13	100	-	-	14.1	-	-	2.2	-	-
MED*199*03	220*	280	280	24.4	14.8	18.4	1.1	3.4	1.2
MED*205*18	160	280	280	9.1	15.2	8.7	1.7	3.1	3.8
SWR*277*08	50	40	60	9.8	25.6	13.2	0.4	0.3	0.6
TRS*160*12	100	280	320	13.2	5.9*	5.1*	0.4	2.1	1.6
TUR*022*17	125	250	250	4.4*	4.6*	4.0*	1.9	3.2	2.8
TUR*156*16	125	250	300	12.0	8.4	7.4	3.0	2.5	2.2
TUR*170*22	100	320	320	15.2	8.7	9.2	2.8	2.9	-1.7
TUR*173*05	100*	200*	200*	39.4	65.6	38.5	0.9	-.3	1.1
TUR*175*04	120	240	280	31.0	23.8	14.0	3.4	5.2	4.0
TUR*186*06	100	240	-	8.3	13.7	-	2.1	0.5	-
TUR*198*02	120	320*	320*	575.4	335.1	270.0	2.3	3.7	3.6

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO
PAGE 3 OF 16

REGION 'TUR' - GREECE,TURKEY,BLACK SEA,E EUROPE,E MEDITERRANEAN

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
TUR*206*10	100	320	320	34.2	24.4	19.2	1.9	3.6	2.2
WKZ*233*02	60	90	75	11.2	27.8	22.5	0.1	0.9	1.1
WRS*204*05	80	120	120	23.4	58.4	44.0	1.4	0.5	1.3
						MEAN SNNR IMPROVEMENT =	1.89	2.78	2.52
						STANDARD DEVIATION =	1.37	1.95	1.91
						NUMBER OF EVENTS =	32	28	25

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

REGION 'CAS' - CASPIAN SEA, EASTERN CAUCASUS

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
CAS/135/04	287	69	69	0.0	0.0	0.0	3.4	1.2	1.0
CAU/262/06	-	392	-	-	0.0*	-	-	0.0	-
CAU/288/17	305	453	453	0.0	0.0	0.0	2.5	2.3	3.4
WKZ/356/06	261	174	174	0.0	0.0	0.0	1.9	1.4	1.2
CAU*166*00	350	300	300	22.6	74.4	44.0	0.2	1.3	1.0
IRA*018*21	300*	600	600	43.1	16.7	13.3	-1.2	3.9	1.5
					MEAN SNNR IMPROVEMENT =		2.00	2.03	1.63
					STANDARD DEVIATION =		1.34	1.13	1.01
					NUMBER OF EVENTS =		4	5	5

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

REGION 'IRA' - SOUTHERN IRAN

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
IRA*006*09	300*	420	-	47.4	31.1	-	-2.4	0.8	-
IRA*014*22	250*	560	560	93.6	33.4	19.8	-2.1	-.8	2.1
IRA*041*09	200	440	440	21.8	7.7	6.6	-.8	1.7	2.6
IRA*041*16	450	400	400	11.8	23.5	8.5	0.9	0.0	1.0
IRA*068*21	350	-	400	19.4	-	22.8	0.2	-	2.7
IRA*155*08	160*	360	-	11.3	3.9*	-	0.4	1.7	-
IRA*156*03	-	540	540	-	3.3*	4.7*	-	5.5	0.6
IRA*157*11	160*	300	360	45.4	8.8	8.8	-2.3	1.7	-1.1
IRA*162*19	160*	480	480	63.6	20.7	15.9	-1.6	2.3	3.5
IRA*164*13	100	350	350	367.0	68.4	76.3	0.6	2.3	1.5
IRA*165*00	160	540	480	444.9	148.0	120.0	-.4	3.4	3.5
IRA*168*23	160*	300	300	22.2	24.4	8.9	-2.4	0.7	1.2
IRA*175*08	160*	300	300	100.4	25.3	21.3	-.8	3.8	2.9
IRA*184*12	200*	-	-	1772.2	-	-	-1.6	-	-
IRA*184*14	90	350	300	2.9*	2.4*	2.6*	1.7	2.2	0.2
IRA*185*02	-	300	300	-	32.5	21.5	-	3.2	3.4
IRA*185*12	-	350	-	-	7.7	-	-	0.5	-
IRA*185*21	100	350	300	242.6	97.8	93.3	1.3	4.2	3.9
IRA*187*16	100	250	250	15.6	21.8	21.4	3.8	2.4	1.3
IRA*187*21	130	-	-	3.2*	-	-	1.4	-	-
IRA*188*05	-	350	350	-	6.1	5.7*	-	1.6	0.7
IRA*193*22	-	200	200	-	54.2	57.0	-	3.3	2.8
IRA*196*13	100	400	-	21.3	7.3	-	0.9	0.6	-
IRA*196*17	100	-	-	6.1	-	-	1.1	-	-
IRQ*060*08	250	400*	400*	11.7	3.5	4.4*	1.1	1.7	-2.4
						MEAN SNNR IMPROVEMENT =	0.87	1.86	2.23
						STANDARD DEVIATION =	1.25	1.42	1.35
						NUMBER OF EVENTS =	10	17	14

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO
PAGE 6 OF 16

REGION 'PAK' - PAKISTAN, EASTERN IRAN

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
IRA*029*09	200	360	360	4.2*	6.1	3.9*	-1.0	-1.2	0.9
IRA*193*15	220	-	-	4.2*	-	-	2.9	-	-
IWP*028*10	240	250*	250*	38.9	31.3	24.4	0.0	-.3	-2.1
PAK*157*11	240	160	320	26.1	14.8	14.0	3.2	1.1	1.1
PAK*162*11	-	300	250	-	46.6	32.6	-	2.3	1.4
PAK*179*10	280	240	160	48.5	132.1	83.5	0.7	2.1	1.7
PAK*195*18	-	240	-	-	6.5	-	-	2.8	-
				MEAN SNNR IMPROVEMENT =			1.30	1.41	1.41
				STANDARD DEVIATION =			1.70	1.61	0.28
				NUMBER OF EVENTS =			3	5	3

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO
PAGE 7 OF 16

REGION 'TDZ' - TADZHIK, KIRGIZ, HINDU KUSH, N AFGANISTAN

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
KRG/301/13	122	383	383	0.0	0.0	0.0	1.5	2.9	1.8
TDZ/147/00	348	392	-	0.0	0.0	-	2.1	3.6	-
TDZ/274/16	348	479	479	0.0	0.0	0.0	-3.2	3.7	3.8
AFG*059*18	250	-	400	6.6	-	13.5	3.8	-	4.2
AFG*181*03	300*	400*	400*	54.1	65.6	50.2	-.6	-1.0	0.9
HNK*053*08	250	350	250	7.8	4.5*	3.7*	2.1	0.9	2.0
HNK*177*07	380	-	-	48.7	-	-	-1.4	-	-
KRG*006*06	80	100	130	4.1*	9.7	6.7	-1.5	0.3	2.2
TAD*077*09	400	350	350	69.3	136.3	121.0	1.3	1.0	1.7
TDZ*005*12	450	450	450	6.7	6.6	6.6	2.3	0.9	0.5
HNK*178*20	-	700	700	-	4.6*	5.0*	-	3.2	2.6
HNK*179*15	-	200	200	-	107.7	76.2	-	2.1	2.5

	LQT	LRV	LRR
MEAN SNNR IMPROVEMENT =	1.07	2.07	2.38
STANDARD DEVIATION =	2.25	1.38	1.26
NUMBER OF EVENTS =	8	7	7

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

REGION 'TIB' - S SINKIANG, TIBET, N BURMA, HIMLAYAN MOUNTAINS

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
SIN/219/15	174	305	305	0.0	0.0	0.0	3.1	3.0	0.3
SIN/241/15	-	174	-	-	0.0*	-	-	0.7	-
TIB/123/00	196	305	305	0.0	0.0	0.0	4.5	1.2	3.5
TIB/155/20	305	479	479	0.0	0.0	0.0	3.2	1.0	1.6
TIB/302/17	217	87	87	0.0	0.0	0.0	2.3	1.0	1.2
BUR*160*16	350	600	700	19.7	26.5	13.7	3.2	-1.4	-.4
CHI*154*16	250	420	420	42.8	16.5	13.8	2.4	3.8	3.1
IND*154*20	250	640	-	10.8	7.5	-	1.9	-.7	-
TIB*075*06	300	300	300	40.7	37.1	24.0	0.7	2.0	2.8
TIB*160*23	120	100	175	16.4	5.8*	5.2*	1.9	1.0	2.3
TIB*170*04	240	360	360	35.2	36.2	14.3	-.8	3.2	1.1
TIB*195*05	200	-	-	6.7	-	-	3.2	-	-
TIB*198*02	250	-	-	66.4	-	-	3.4	-	-
TIB*198*03	200	-	-	10.6	-	-	2.0	-	-
TIB*204*16	150	200	200	5416.3	936.4	511.8	2.8	1.3	-1.0
TIB*204*21	150	-	-	27.9	-	-	3.7	-	-
TIB*205*23	150	-	-	8.6	-	-	3.5	-	-
TIB*206*14	150*	200*	200*	20.9	20.7	15.3	-.7	1.2	0.8
					MEAN SNNR IMPROVEMENT =		2.56	1.43	1.35
					STANDARD DEVIATION =		1.27	1.65	1.58
					NUMBER OF EVENTS =		16	10	9

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO
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REGION 'CHI' - CENTRAL CHINA

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LOT	LRV	LRR	LOT	LRV	LRR	LOT	LRV	LRR
CHI/229/09	152	479	479	0.0	0.0	0.0	2.3	4.0	4.3
CHI/229/17	152	196	196	0.0	0.0	0.0	1.6	1.9	1.4
CHI/258/07	174	471	471	0.0*	0.0*	0.0*	2.5	3.2	3.1
CHI*034*07	180	550	550	37.7	12.3	9.7	2.3	1.9	2.3
CHI*189*23	380	-	-	15.9	-	-	1.5	-	-
CHI*203*16	310	400	400	38.3	69.6	29.9	5.8	3.6	4.6
MON*153*11	200	-	-	9.9	-	-	1.7	-	-
YUN*057*18	300	300	600	45.7	33.2	20.3	0.5	-.3	-1.4
						MEAN SNNR IMPROVEMENT =	2.24	2.22	2.26
						STANDARD DEVIATION =	1.67	1.71	2.43
						NUMBER OF EVENTS =	7	5	5

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

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REGION 'SIN' - SOUTHWESTERN, WESTERN, NORTHWESTERN SINKIANG

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
SIN/166/22	87	174	174	0.0	0.0	0.0	1.6	1.2	0.0
SIN/166/23	95	217	217	0.0	0.0	0.0	1.4	-.6	-.2
SIN/170/17	108	217	217	0.0	0.0	0.0	0.7	1.3	1.9
SIN/221/01	104	78	78	0.0	0.0	0.0	1.9	0.6	0.3
CRS/236/16	113	239	-	0.0	0.0	-	2.6	2.5	-
SIN/273/12	104	174	174	0.0	0.0	0.0	1.7	1.5	0.4
BAI*058*22	100	300	300	7.7	12.2	8.4	1.2	2.7	2.5
FKZ*078*07	-	50	50	-	4.7*	3.3*	-	0.4	1.3
KRG*028*20	80	320*	320*	9.7	4.5	3.7*	0.8	-1.8	-1.3
SIN*002*10	80	100	100	70.4	75.8	62.4	2.5	1.1	1.0
SIN*042*05	100*	100	100	53.3	70.6	52.6	0.9	1.1	0.4
SIN*047*23	80	150	150	17.1	31.8	22.4	0.8	0.5	0.8
SIN*064*04	100	200	200	19.3	44.6	19.1	-.2	0.7	1.0
SIN*154*06	80	175	-	29.0	5.8*	-	1.5	1.2	-
SIN*187*01	60	175*	175*	256.0	78.2	53.0	1.1	1.5	2.3
SIN*187*04	140	175	175	8.0	12.7	8.4	4.2	3.2	2.5
SIN*192*19	160	175	175	6.9	35.6	26.4	3.2	1.6	1.1
SIN*200*03	100	-	-	7.6	-	-	0.7	-	-
						MEAN SNNR IMPROVEMENT =	1.60	1.34	0.97
						STANDARD DEVIATION =	1.08	1.01	0.89
						NUMBER OF EVENTS =	16	13	12

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO
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REGION 'EKZ' - EASTERN KAZAKH TEST AREA, CENTRAL KAZAKH

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
EKZ/145/04	-	113	-	-	0.0*	-	-	4.0	-
EKZ/157/04	91	200	200	0.0	0.0	0.0	1.3	1.8	0.2
EKZ/170/04	52	139	139	0.0	0.0	0.0	0.5	0.3	1.8
EKZ/282/06	-	139	-	-	0.0*	-	-	2.7	-
EKZ/294/06	39	122	122	0.0	0.0	0.0	0.9	0.8	-1.6
EKZ/333/06	52	69	69	0.0	0.0	0.0	1.4	0.5	1.1
EKZ/364/06	65	87	87	0.0	0.0	0.0	1.3	1.1	1.2
EKZ*070*04	50	100	100	10.0	9.9	6.6	1.0	1.4	1.2
EKZ*088*04	130	50	50	2.8*	4.0*	3.2*	4.2	0.1	0.3
EKZ*229*03	-	60	80	-	6.3	5.4*	-	0.2	0.1
EKZ*307*01	-	75	-	-	29.0	-	-	1.8	-
EKZ*345*04	50	50	75	77.3	34.0	29.1	-.3	0.9	1.1
KAZ*181*00	-	-	100	-	-	4.7*	-	-	1.4
						MEAN SNNR IMPROVEMENT =	0.87	0.97	0.71
						STANDARD DEVIATION =	0.61	0.60	1.12
						NUMBER OF EVENTS =	7	9	7

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO
PAGE 12 OF 16

REGION 'TAI' - TAIWAN, S RYUKYU ISLANDS, EAST CHINA SEA

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
CHI*028*04	600*	700	700	11.3	7.5	6.9	-2.4	0.0	2.2
RYU*155*02	300	500	500	108.3	101.7	66.5	1.2	3.6	5.0
RYU*197*02	240	520	520	24.2	48.0	34.1	3.1	3.0	3.6
RYU*209*16	360	640	640	261.4	106.8	68.5	2.9	3.9	1.3
TAI*004*05	500*	1000	-	5.0	3.2*	-	2.9	1.8	-
TAI*004*12	400*	600	600	97.9	64.0	50.2	2.4	1.5	3.1
TAI*006*06	500*	600	600	19.7	10.5	13.5	0.3	0.1	-.9
TAI*010*05	700	800	800	50.6	20.0	17.7	0.2	4.9	3.8
TAI*178*08	300	500	500	158.7	94.8	81.4	2.3	4.2	4.3
TAI*182*18	300*	500	500	548.8	153.3	80.1	3.7	0.8	2.4
TAI*195*23	300	-	-	20.1	-	-	6.0	-	-
TAI*198*13	300	400	400	30.0	55.8	26.4	3.6	3.8	4.1
						MEAN SNNR IMPROVEMENT =	2.74	2.59	2.89
						STANDARD DEVIATION =	1.85	1.81	1.75
						NUMBER OF EVENTS =	7	10	10

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

REGION 'KUR' - KURILE ISLANDS FROM JAPAN TO KAMCHATKA

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LOT	LRV	LRR	LOT	LRV	LRR	LOT	LRV	LRR
KUR/135/21	828	806	806	0.0	0.0	0.0	-.6	4.8	4.1
KUR/146/01	566	762	762	0.0	0.0	0.0	5.7	6.8	6.2
KUR/147/16	479	828	828	0.0	0.0	0.0	6.3	4.8	7.1
KUR/152/21	566	697	697	0.0	0.0	0.0	2.7	5.9	4.9
KUR/190/16	828	1002	1002	0.0	0.0	0.0	6.9	4.4	4.6
KUR/191/03	741	958	958	0.0	0.0	0.0	6.2	4.0	7.2
KUR/191/09	523	871	871	0.0*	0.0*	0.0*	0.5	0.8	0.5
KUR/213/02	459	893	893	0.0	0.0	0.0	4.7	8.7	7.9
KAM*078*18	980	-	-	3.6*	-	-	1.8	-	-
KUR*001*16	700	-	-	3.4*	-	-	1.2	-	-
KUR*001*18	-	700	-	-	4.5*	-	-	0.0	-
KUR*005*02	700	900	900	4.7*	4.7*	3.6*	2.6	6.1	6.2
KUR*009*14	-	-	900	-	-	2.2*	-	-	2.0
KUR*022*01	-	700	1150	-	3.5*	4.4*	-	1.0	0.0
KUR*028*23	980	-	-	3.4*	-	-	-4.3	-	-
KUR*046*16	860	850	850	3.4*	4.8*	2.9*	0.5	5.0	4.2
KUR*049*18	860	850	850	4.2*	4.9*	3.8*	3.8	-.8	1.7
KUR*054*03	620	1000	1000	36.8	26.6	23.3	2.9	0.7	0.3
KUR*054*27	740	1000	1000	25.0	19.6	16.9	3.8	2.2	2.7
KUR*054*37	620	1000	1000	30.7	24.4	21.7	3.1	1.1	0.9
KUR*055*10	980	1000	1000	46.7	134.4	90.4	3.5	5.7	5.7
KUR*056*22	620	700	700	3.5*	4.0*	3.7*	1.8	-1.5	0.3
KUR*057*02	980	700	700	46.6	132.5	102.1	2.7	1.8	0.6
KUR*057*05	980	850	850	6.8	7.4	6.6	3.4	7.1	7.9
KUR*063*23	740	1000	1000	4.5*	11.8	6.4	3.0	6.1	10.8
KUR*070*06	620	850	-	3.5*	3.0*	-	2.3	1.8	-
KUR*077*07	980	-	-	11.4	-	-	4.6	-	-
KUR*153*00	500*	700	700	8.5	6.0*	6.6	3.6	4.2	3.2
KUR*169*19	740	1000	1300	11.2	10.7	5.7*	2.5	3.7	0.8
KUR*171*18	980	700	1150	14.3	20.7	9.2	0.2	0.6	3.9
KUR*171*22	-	1000	-	-	5.8*	-	-	3.7	-
KUR*190*21	500	850	1000	2.7*	5.0*	3.0*	3.9	1.6	4.5
KUR*193*06	-	850	-	-	51.1	-	-	7.0	-
KUR*194*00	860	850	1000	23.3	53.5	39.4	4.5	7.7	7.4
KUR*195*15	500	700	700	4.8*	9.9	6.5	4.7	4.7	2.7

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO
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REGION 'KUR' - KURILE ISLANDS FROM JAPAN TO KAMCHATKA

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRR	LQT	LRV	LRR	LQT	LRV	LRR
KUR*211*21	500	700	700	55.6	81.1	34.6	2.4	1.7	2.8
					MEAN SNNR IMPROVEMENT =		3.64	4.48	4.77
					STANDARD DEVIATION =		1.98	2.46	2.84
					NUMBER OF EVENTS =		18	20	19

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO
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REGION 'KAM' - KAMCHATKA PENINSULA, KOMANDORSKY ISLANDS

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LOT	LRV	LRR	LOT	LRV	LRR	LOT	LRV	LRR
KAM/166/14	610	1046	1046	0.0	0.0	0.0	-.1	1.3	0.8
KOM/148/10	523	697	697	0.0	0.0	0.0	0.0	4.6	6.3
KAM*003*06	560	700	700	12.5	16.5	14.3	5.3	2.0	3.6
KAM*003*19	700	-	-	3.5*	-	-	0.8	-	-
KAM*004*02	600	900	800	3.6*	3.0*	2.7*	-1.2	2.3	2.1
KAM*005*16	620	850	850	3.6*	3.4*	3.7*	3.7	1.8	-.3
KAM*009*14	620	-	-	3.7*	-	-	-1.1	-	-
KAM*012*20	500	1050	1200	15.1	13.3	11.2	2.4	1.4	4.6
KAM*042*21	740	1000	850	6.6	6.2	6.9	-.2	2.0	-1.6
KAM*052*22	-	1000	-	-	3.9*	-	-	2.9	-
KAM*156*07	-	1150	-	-	5.3*	-	-	1.4	-
KAM*157*04	620	1300	700	8.2	8.3	6.1	2.6	0.5	1.8
KAM*163*14	-	1000	-	-	5.6*	-	-	0.3	-
KAM*177*17	620	1150	-	9.1	5.6*	-	3.3	4.1	-
KAM*180*14	-	1300	1000	-	3.3*	6.0	-	1.8	0.4
KAM*186*13	-	850	-	-	4.0*	-	-	4.4	-
KAM*189*05	-	1300	-	-	3.2*	-	-	5.9	-
KAM*193*08	500	-	-	4.0*	-	-	2.7	-	-
KAM*197*13	-	1000	-	-	3.2*	-	-	1.3	-
KAM*206*13	-	700	700	-	8.2	6.4	-	2.2	2.3
KOM*044*22	740	700	700	3.3*	3.7*	3.2*	3.0	2.2	2.3
KOM*153*21	980	700	700	6.3	5.9*	6.1	-1.4	2.7	2.7
KUR*209*00	500	1150	1150	104.4	98.1	68.8	6.1	1.9	3.4
						MEAN SNNR IMPROVEMENT =	1.99	1.99	2.42
						STANDARD DEVIATION =	2.62	1.20	2.25
						NUMBER OF EVENTS =	9	8	10

TABLE V-1

CHIRP MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

REGION 'OTHER' - OTHER EVENTS NOT GROUPED

EVENT	CHIRP LENGTH			BANDPASSED SNNR			SNNR IMP (DB)		
	LQT	LRV	LRP	LQT	LRV	LRP	LQT	LRV	LRP
CHI/156/10	183	348	348	0.0	0.0	0.0	3.4	2.2	2.0
CHI/249/21	392	784	784	0.0	0.0*	0.0*	2.1	2.7	2.5
ERS/165/13	174	392	392	0.0	0.0	0.0	4.7	1.0	1.1
ERS/266/21	152	305	305	0.0*	0.0	0.0*	2.9	-.6	0.6
BKL*035*03	200	300	300	3.7	3.9	3.6*	2.1	1.1	0.2
CHI*030*03	150	300	360	16.8	27.9	9.8	2.0	1.5	0.9
ERS*015*19	200	300	300	20.6	13.5	12.1	3.9	0.5	0.8
ERS*172*09	400	-	-	8.7	-	-	-.7	-	-
KAM*051*20	-	850	850	-	2.8	3.1*	-	2.9	-.3
LOM*157*19	320	160	160	16.2	33.3	29.2	2.2	2.4	2.6
NRS*058*10	220	250*	250*	41.3	92.3	63.7	3.9	0.4	1.4
NRS*058*17	220	300	300	4.3*	7.6	6.2	3.1	0.6	1.5
RYU*196*18	-	880	880	-	3.2	3.2*	-	2.4	0.4
SIB*013*17	400	800	800	167.8	366.1	283.3	1.4	5.6	4.4
SIB*014*03	800	600	600	3.3	5.1	5.0*	3.6	4.1	4.8
UAR*180*09	300	460	460	155.6	78.0	99.3	-.3	5.9	4.7

MEAN SNNR IMPROVEMENT = 2.34 2.26 2.24

STANDARD DEVIATION = 1.65 1.95 1.55

NUMBER OF EVENTS = 12 13 9

of the chirps applied to a particular component was considered to be the optimum length, an asterisk was placed next to that length. Second, if the (amplitude) SNNR of the bandpassed signal was less than 6.0 (15.6dB) it was considered to be too noisy to give unbiased results and an asterisk was placed next to the SNNR value.* If an asterisk of either type was placed on that event-component entry, its improvement was not used to compute the average improvement.

The SNNR improvements obtained by chirp filters range from about 0.8 dB for region EKZ to about 3.5-4.5 dB for region KUR. Median improvement is 2 dB. Overall, chirps applied to Love waves yield slightly less gain than chirps applied to Rayleigh waves (vertical). There are significant differences however in LQ-LR behavior from region to region. For example, in KUR, TDZ, and IRA, LQ gains were 1 dB smaller than LR gains; while in TIB the reverse was true. Five regions had LQ > LRV gains and seven regions with LQ < LRV gains.

Physical considerations indicate that the chirp gains for the vertical and radial components should be similar; hence the ratio of vertical to radial gains should be near unity. The average ratio, computed over 145 events, is 1.009 (0.04 dB).

The standard deviations (sigmas) of the SNNR improvements are in many cases larger than the mean improvements, although most values are about 0.6 of the mean. Large means tend to have large sigmas and vice-versa. Some regions and wave components which show relatively small sigmas include ITA (LQ), TDZ (LR), and EKZ (LQ, LRV). Regions with a relatively large sigma include ITA (LR), IRA (LQ), TDZ (LQ), TIB (LR), and KAM (LQ).

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* Bandpassed SNNR's of the 1971 events are shown as 0.0 however they also were checked for actual SNNR.

The ratio of the standard deviations of the radial and vertical components of LR should also be approximately equal to unity. This is generally the case with nine regions having values between 0.85 and 1.15. Three regions, PAK, EKZ, and KAM showed unusually large or small sigma ratios.

The sole purpose of using matched filters is to lower the detection threshold so that more smaller events can be detected. The surface wave magnitudes assigned to such events include a correction factor to account for the matched filter gain. What factor is used should be a function of mean gain and the standard deviation computed so as to satisfy whatever probabilistic detection model is used. In this report, magnitude correction factors were computed using the mean gain of each region.

The regionalization scheme based on chirp length does not reflect as clearly any SNNR gain differences between regions, primarily because of the large gain variances. For example, the small region TDZ, which had long chirp lengths, has small LQ gains and larger LR gains. On the other hand, the three regions contiguous to TDZ, PAK, TIB, and SIN, all have large LQ gains and smaller or equal LR gains. The event KRG*006*06 in region TDZ actually lies on the TDZ-SIN regional boundary. It has the short chirp lengths appropriate to region SIN even though its SNNR gain behavior, considering its low SNNR, is more like TDZ than SIN. A second example is the region KAM, which shows a distinctly different mean gain and standard deviation than the main Kurile Island region KUR even though these two regions have similar chirp lengths.

The region EKZ was differentiated from SIN primarily because events there were mostly presumed explosions rather than because of inherent differences in chirp behavior. EKZ events have the smallest variance in gain for LRV (LQ gain variance was the second smallest) of any region observed. The presumed source mechanism and small geographical distribution are

most likely the reasons for this. Similarity of source mechanism and location also contribute to the small LQ gain variance for the ITA events. If only the Italian events are considered in this region, the LR gains would also have less variance. Interestingly, the Austrian and northwestern Yugoslovian events show similar LQ gains but distinctly larger LR gains than do the Italian events.

Chirp gains obtained at NORSAR are similar to those obtained at ALPA (Strauss, 1973). Typical gains for events at comparable distances were generally fairly close, except for a few areas where most gain differences could be attributed to differences in chirp length. For example, ALPA showed larger gains both in eastern Kazakh and in Taiwan. Best (Rayleigh) chirp lengths for Kazakh events was about 700 seconds for ALPA but only 50-100 seconds for NORSAR. For Taiwan, ALPA lengths were about 800 seconds compared to 300 seconds for NORSAR.

The application of chirp filters to the data produced eleven event detections where the surface waves had been undetected on the bandpassed beam. Ten of these events had m_b's between 3.6 and 4.2, which brackets the 50% detection level*, and constituted about 9 percent of the detected events in that range.

E. REFERENCE WAVEFORM FILTER RESULTS

Reference waveform filters (RWF) were used on groups of events from three areas only: the eastern Kazakh test area, central Italy near Ancona, and a small area midway between the Kamchatka Peninsula and the Komandorsky Islands. The first two groups were events which originated from small areas and, within each area, presumably had the same source mechanism. The Kamchatka events, except for the reference

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* Section VI

waveform event itself, were all small and had been undetected using both bandpass and chirp filters.

Processing of these events was similar to the chirp filtering and used the same beam data. After applying the RWF, the output was then bandpass filtered. SNNR improvements were compiled as for the chirps.

The Kamchatka events are listed in Table V-2. Except for the reference event, none of these events were detected using the reference waveform filter. The SNNR improvement of KAM*012*20 when applied to itself was between 4.5-6.0 dB implying a magnitude boost of 0.2-0.3 units. Allowing for this gain, the probability of detection for the m_b = 3.9-4.3 range would be between 40 and 80 percent.* Included in Table V-2 are the results obtained from ALPA data (Strauss, 1973). ALPA detected only six out of ten of these events and the surface wave magnitudes of five of these tend to be disproportionately smaller than the given m_b. It is likely that at least a few of the events have an erroneously large m_b or are deep.

RWF SNNR improvements for the Italian and Kazakh events are listed in Table V-3. The event used as a reference waveform is listed first. Kazakh SNNR improvements from the RWF show a distinctly different behavior from those from the chirp filters. The vertical and radial Rayleigh wave gains are about 2 dB more than the chirp gains, while Love wave improvements with the RWF, surprisingly, are 1 dB less than with the chirp. The decrease can be attributed mostly to the event EKZ*345*04 which was actually a double event with origin times about ten seconds apart** and which had unusually large Love waves. The exact cause for negative improvement is unknown other than that their Love waves are obviously mismatched.

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* Section VI

** from NOAA-ERL Preliminary Determination of Epicenters Bulletin

TABLE V-2

REFERENCE WAVEFORM FILTERED KAMCHATKA EVENTS

Event	m_b	ALPA	
		M_{sr}	M_{sl}
KAM*012*20(RWF)	4.8	4.0	4.2
KAM*004*10	4.4	ND	ND
KOM*009 03	3.6	ND	ND
KAM*016*04	3.8	2.5	2.4
KAM*016*11	3.9	ND	ND
KAM*027*20	3.8	2.8	3.4
KAM*032*10	4.1	2.4	2.7
KAM*033*14	3.7	ND	ND
KAM*059*11	4.1	2.5	ND
KAM*059*20	3.6	3.0	3.4
KOM*063*08	4.1	2.3	2.7

TABLE V-3

REFERENCE WAVEFORM MATCHED FILTER IMPROVEMENT IN SIGNAL+NOISE/NOISE RATIO

REGION 'EKZ' - EASTERN KAZAKH TEST AREA

EVENT	FILTER	BANDPASSED SNNR LQT	LRV	LRR	SNNR IMP (DB) LQT	LRV	LRR
EKZ/364/06	EKZ364/A2048	0.0	0.0	0.0	2.0	2.8	3.2
EKZ/157/04	EKZ364/A2048	0.0	0.0	0.0	0.2	2.2	-.6
EKZ/170/04	EKZ364/A2048	0.0	0.0	0.0	1.3	2.0	4.6
EKZ/294/06	EKZ364/A2048	0.0	0.0	0.0	0.1	3.5	0.9
EKZ/333/06	EKZ364/A2048	0.0	0.0	0.0	0.4	2.9	1.8
EKZ*088*04	EKZ364/A2048	-	4.0*	-	-	1.6	-
EKZ*229*03	EKZ364/A2048	-	6.3	5.4*	-	1.5	2.0
EKZ*307*01	EKZ364/A2048	20.9	29.0	18.0	-.2	4.8	2.5
EKZ*345*04	EKZ364/A2048	77.3	34.0	29.0	-1.6	3.9	4.5
				MEAN SNNR IMPROVEMENT =	0.03	2.97	2.28
				STANDARD DEVIATION =	0.95	1.17	2.04
				NUMBER OF EVENTS =	6	7	6

REGION 'ITA' - CENTRAL ITALY

EVENT	FILTER	BANDPASSED SNNR LQT	LRV	LRR	SNNR IMP (DB) LQT	LRV	LRR
ITA*035*02	ITA035AA2048	224.4	62.7	53.3	3.5	0.4	1.0
ITA*035*04	ITA035AA2048	3.8*	-	-	1.3	-	-
ITA*035*09	ITA035AA2048	131.3	31.4	24.5	2.4	-2.3	-1.6
ITA*035*17	ITA035AA2048	114.6	29.5	25.7	2.4	0.6	0.1
ITA*035*19	ITA035AA2048	25.9	8.6	4.4*	1.6	1.2	1.6
ITA*036*07	ITA035AA2048	38.4	23.3	19.8	1.8	-3.3	-.2
ITA*036*15	ITA035AA2048	98.3	34.8	34.6	1.8	1.2	-.4
ITA*037*01	ITA035AA2048	88.0	22.1	24.1	2.4	-.6	0.2
ITA*037*21	ITA035AA2048	12.7	-	-	3.3	-	-
ITA*039*12	ITA035AA2048	23.9	10.4	10.4	2.0	-.6	2.7
				MEAN SNNR IMPROVEMENT =	2.21	-0.54	0.10
				STANDARD DEVIATION =	0.54	1.74	1.41
				NUMBER OF EVENTS =	8	7	6

The ten Italian events were characterized by Love waves which were virtually identical, not only in the primary arrival but in the scattered energy received up to 1200 seconds later (source-to-array travel time was about 450 seconds and duration about 300 seconds). This scattered energy had decayed to background level at 1200 seconds but was still coherent event-to-event. The Rayleigh waves, however, were weak, confused, and relatively narrow-band and seemed to be of two types. Type "B" were the waves from ITA*035*09 and ITA*036*07 while the remaining eight were of type "A". These two types were almost identical, differing only by a slight phase shift in the waveform about midway through the signal. Both 'B' events had exceptionally low (negative) improvement. Excluding the 'B' events, RWF and chirp filter SNNR gains were about the same for the Rayleigh waves. RWF gains for the Love wave were about 1 dB larger than the chirp gains.

Considering the close similarity of the Love waves of the ITA events, it was puzzling at first as to why the SNNR gains were not the same as for the RWF applied to itself. This phenomenon was also evident in the chirp filtering results. It was discovered that the method of measuring true SNNR, described in part B of this section, is not always valid. The assumptions of this method are that the noise has no signal energy present and that the bandpass filter and the RWF differ mainly in average filter amplitude and that the difference can be calibrated. In many situations, these assumptions are not true when the noise spectrum is altered by the presence of signal energy from previous events. The non-white spectrum of the RWF gives a different average output when the spectrum of the input data changes even though the RMS level remains the same. Since the filter spectrum (in the processing band) is flat for the bandpass and chirp filters but not for the RWF, the apparent gain of the RWF is sensitive to changes in the noise spectrum. This sensitivity results in a RWF gain which is not constant but is dependent on the statistics of the beam "noise" at the time of application. An example of this sensitivity is the behavior of the RWF on the swarm of Italian

events beginning on 4 February 1972. The first event, used as the RWF, was followed by several large reported events and probably also by numerous unreported aftershocks. Table V-4 gives the ratios of the outputs of the RWF and bandpass filters, the chirp and bandpass filters, and the RWF and chirp filters to both signals (Love wave) and noise for the Italian events.

The pertinent numbers in Table V-4 are the means and standard deviations (S. D.) of the various ratios. The standard deviation of the ratio of the RWF and bandpass outputs on the signal gate is small (equivalent to less than 0.2 dB). This is true also for the ratios of the chirp to bandpass and RWF to chirp. Conversely, the same ratios on the noise have standard deviations three to six times larger. Thus the variation in SNNR gain obtained by RWF (and chirps to a lesser extent) for essentially identical events is due to subtle changes in the noise spectrum brought about by remnant signal energy, and not to any variation in response to the signal itself.

The consequences of this effect are that the average gain of a RWF should not be computed from an earthquake swarm and that the effectiveness of a RWF may be reduced if interfering signal energy is present at the array during the arrival of a desired event.

TABLE V-4

COMPARISON OF REFERENCE WAVEFORM (ITA*035*02), CHIRP, AND BANDPASS FILTERS ON THE LOVE WAVES OF THE ITALIAN EVENTS COMMENCING 4 FEBRUARY, 1971

Event	Rs/Bs	Rn/Bn	RWF Imp	Cs/Bs	Cn/Bn	Chirp Imp	Rs/Cs	Rn/Cn
35*02	1.904	1.274	1.495	1.172	0.944	1.241	1.625	1.350
35*09	1.892	1.436	1.317	1.181	1.142	1.034	1.602	1.257
35*17	1.903	1.436*	1.325	1.187	1.142*	1.039	1.603	1.257*
35*19	1.920	1.593	1.205	1.211	1.036	1.169	1.585	1.538
36*05	1.909	-	-	1.213	1.075*	1.128	1.574	-
36*07	1.932	1.573	1.228	1.187	1.075	1.104	1.628	1.463
36*15	1.900	1.549	1.227	1.193	0.951	1.254	1.593	1.629
37*01	1.901	1.447	1.314	1.178	0.966	1.220	1.614	1.498
37*21	1.973	1.349	1.463	1.264	1.012	1.248	1.561	1.333
39*12	1.860	1.481	1.256	1.171	1.006	1.165	1.588	1.472
Mean	1.909	1.463	1.313	1.196	1.015	1.179	1.597	1.442
S. D.	0.029	0.111	0.129	0.028	0.085	0.078	0.021	0.121
D. F.	10	8	8	10	8	8	10	8

* RMS noise level obtained from noise of earlier or later event. This data not in statistics

R = RWF
C = Chirp Filter
B = Bandpass Filter

Subscripts:
s Peak amplitude in signal gate
n RMS amplitude in noise gate

SECTION VI

NORSAR LONG-PERIOD SURFACE WAVE DETECTION CAPABILITY

The detection history of the 383 events in the data base was used to estimate the NORSAR long-period surface wave incremental detection probability curve. Smoothed estimates of detection probabilities were obtained by a new method (Ringdal, 1974). This method models detection as a random Gaussian process and obtains maximum-likelihood estimates of the process parameters based on the experimental data at hand. For a detailed description of the theory and its limitations, and a derivation of the likelihood functions, the reader is refered to Ringdal (1974).

Detections were determined independently for each component except for the 1971 events where detections were assessed only on the vertical component. The criteria for detection were:

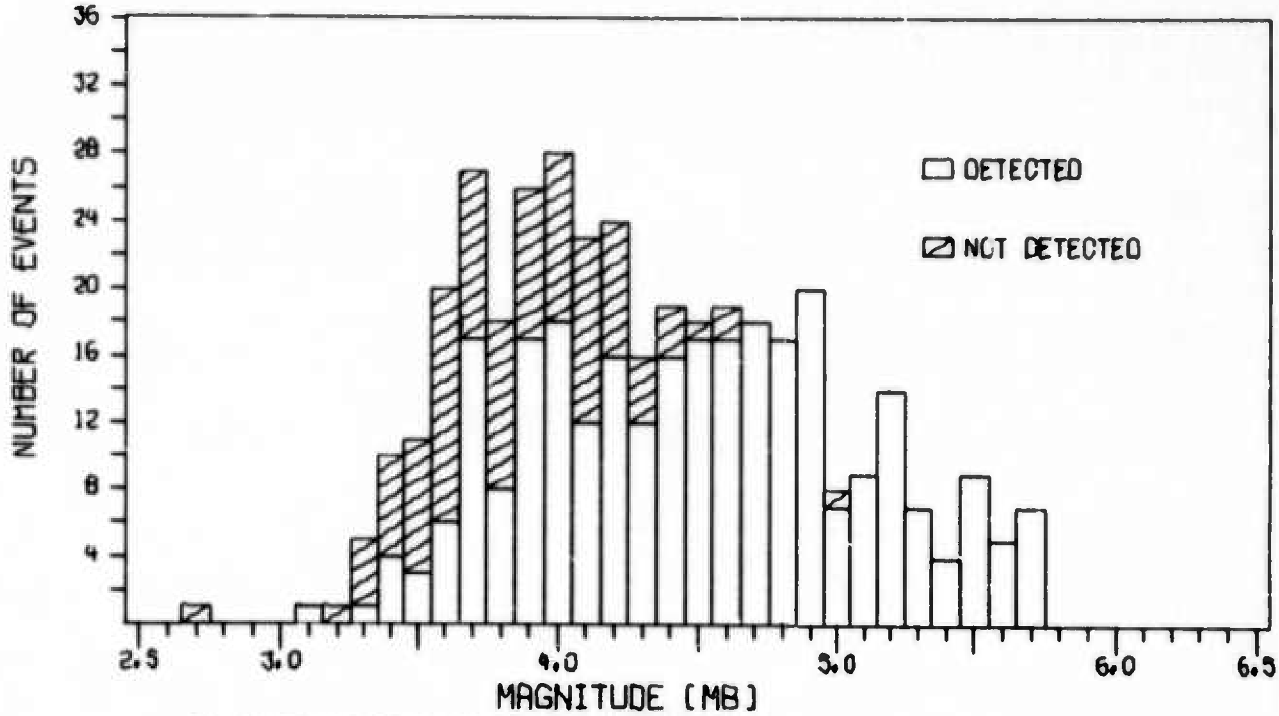
- A peak in the bandpassed or matched filtered trace which was 3 dB larger than any other peak in a 15 to 30 minute time gate centered at the peak occurence time. The width of the time gate was roughly proportional to epicentral distance to account for dispersion.
- The peak should occur within ± 100 to ± 300 seconds, depending on distance, of the expected peak occurrence time.
- Peaks should be signal-like, showing dispersion appropriate for the distance and region. For events detected only by matched filters, the matched filter output peak should be pulse-like from the filter appropriate to the source region and the bandpassed only waveform should show some evidence of signal-like energy.

These criteria were not absolute and for the cases of threshold detection/non-detection, judgement of the analyst played a major part in the decisions. In most cases, that decision was conservative with the result that the false alarm rate was estimated to be less than one percent and that the resulting detection threshold estimates were also conservative. The detection results are presented in Figures VI-1 through VI-8, which include both histograms of the event m_b populations and detection probability curves. In addition to the observed detection percentages and the smooth detection probability curve, the detection probability figures indicate the estimated 50 percent and 90 percent detection m_b levels, the 90 percent confidence limits of those estimates, and the standard deviation (sigma) of the Gaussian distribution fitted to the observed data.

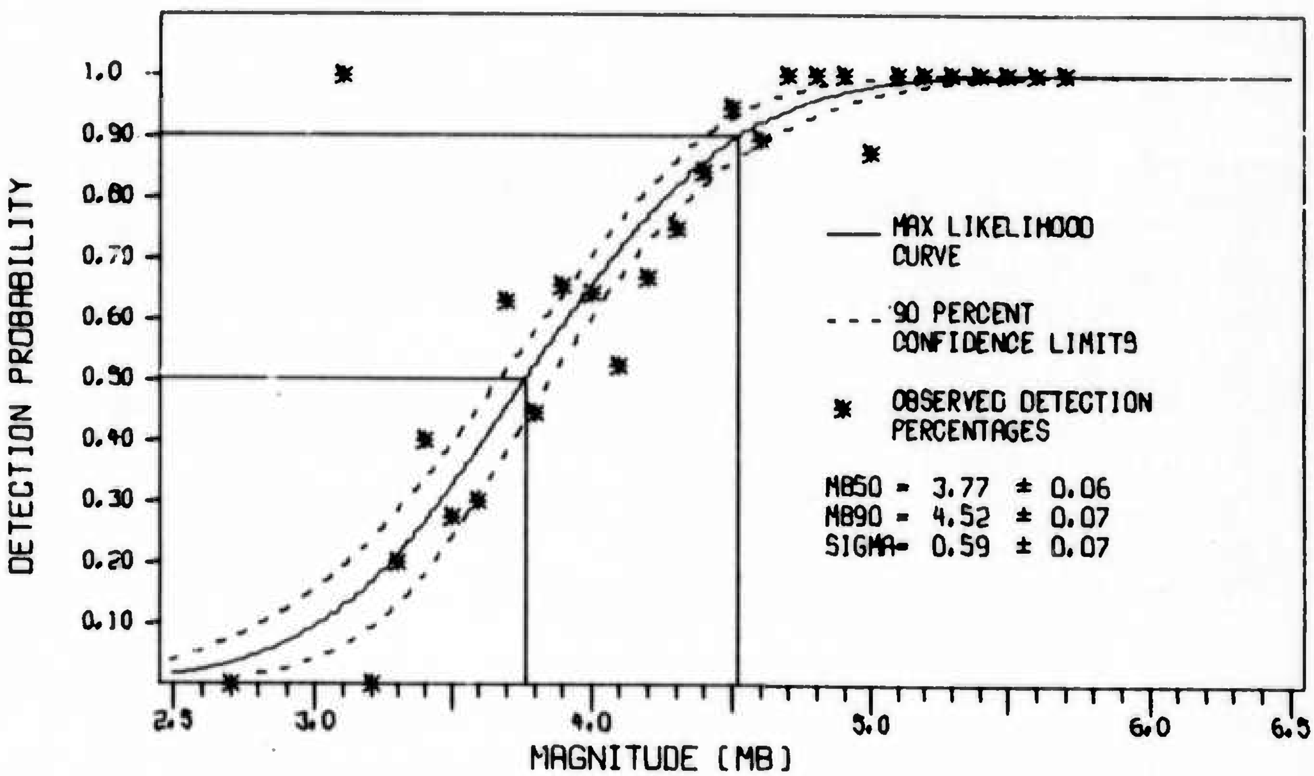
The detection behavior was observed also for summer and winter events, events in the central Asia region and the Kurile-Kamchatka region, and presumed explosions.

The detection results by region are as follows:

- The 90 percent detection level for all events combined, Figure VI-1, was at $m_b = 4.5$. This is slightly better than the estimate of $m_b = 4.5$ using just the 1971 events last year.
- For the Kurile, Kamchatka, Okhotsk region, Figure VI-2, the 90 percent threshold was at $m_b = 4.6$. This is slightly higher than that obtained at ALPA which is 45°-55° closer than NORSAR
- In central Asia, Figure VI-3, NORSAR obtained the 90 percent level at $m_b = 4.5$. These data were must less well-behaved than the Kurile data and thus the estimate is somewhat less reliable. In these regions, ALPA detection thresholds are about the same.
- The group of presumed explosions from the eastern Kazakh test area was very small. Since only two magnitude bins had more



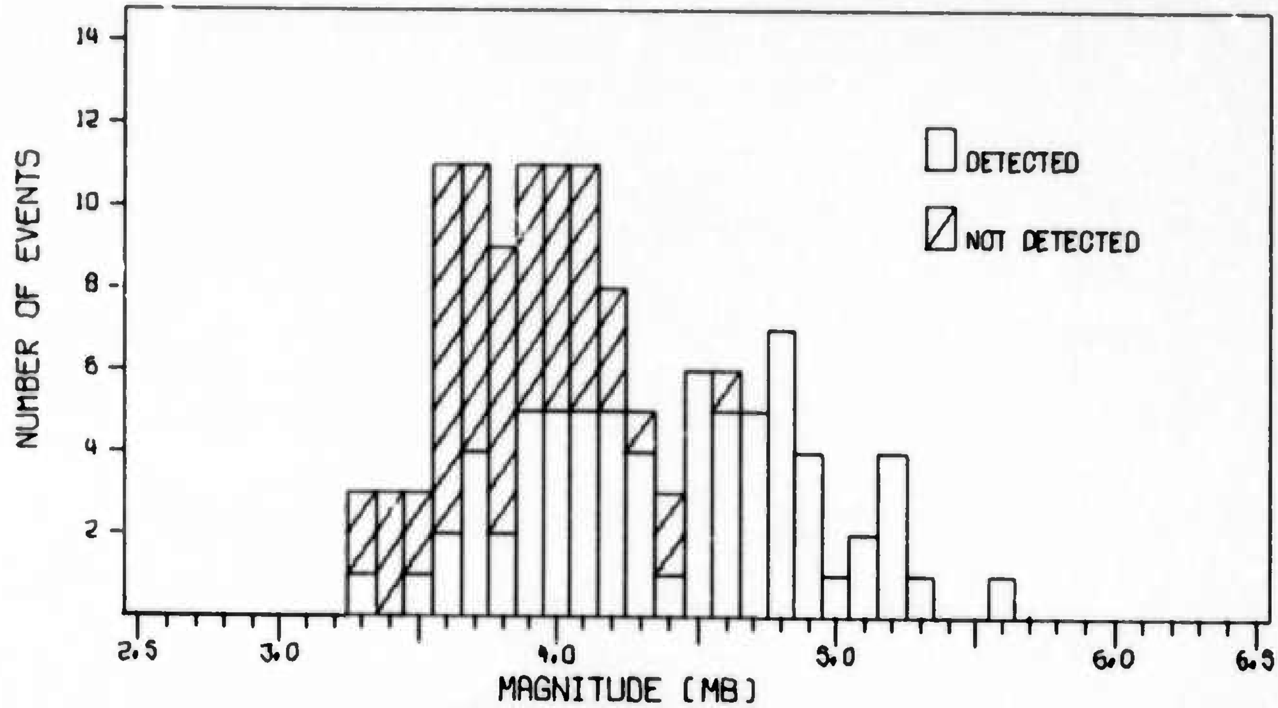
MB DISTRIBUTION OF PROCESSED EVENTS
COMBINED 1971 AND 1972 EVENTS



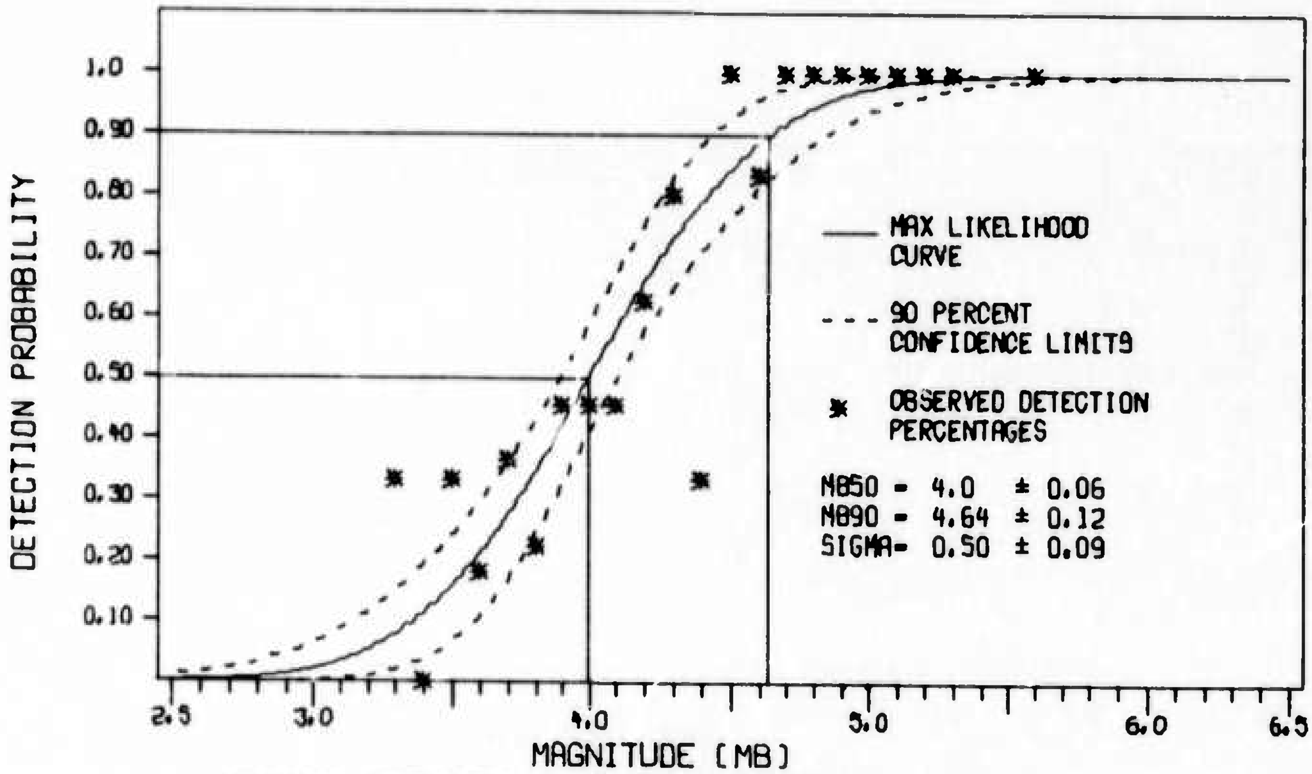
MAXIMUM LIKELIHOOD DETECTABILITY CURVE
COMBINED 1971 AND 1972 EVENTS

FIGURE VI-1

NORSAR LP SURFACE WAVE DETECTION STATISTICS FOR THE COMBINED 1971 AND 1972 EVENT ENSEMBLES



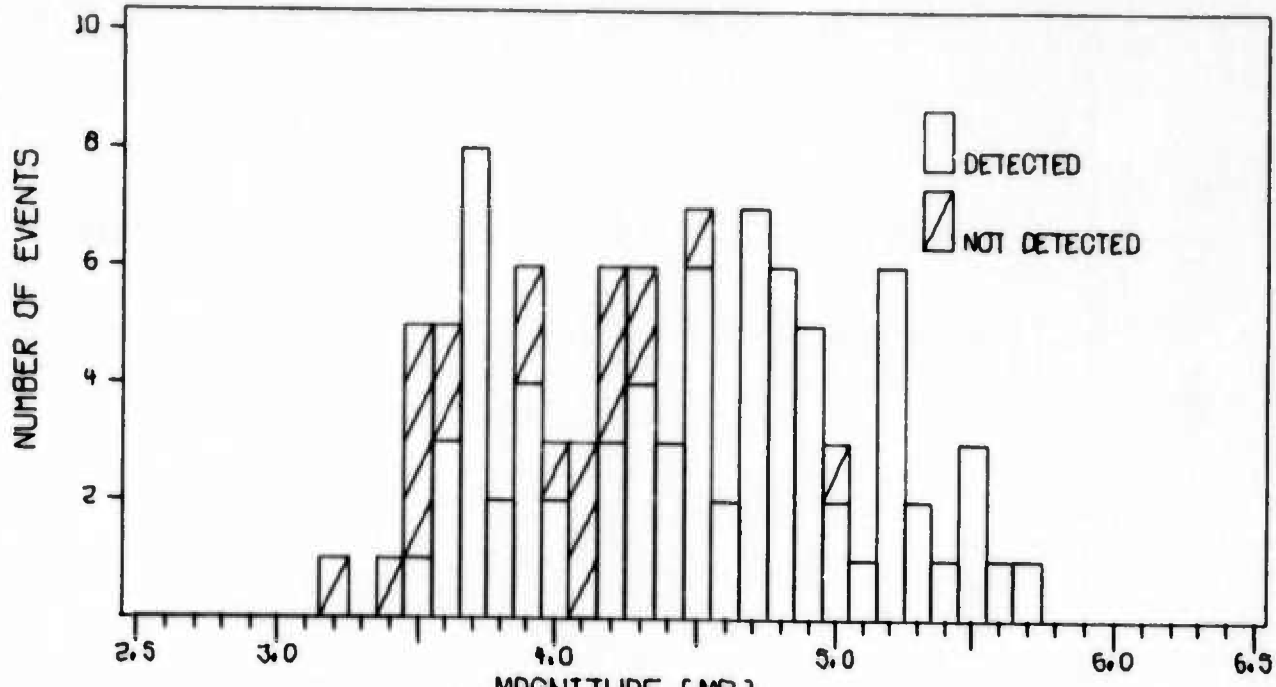
MB DISTRIBUTION OF PROCESSED EVENTS
KURILES. KAMCHATKA. OKHOTSK EVENTS



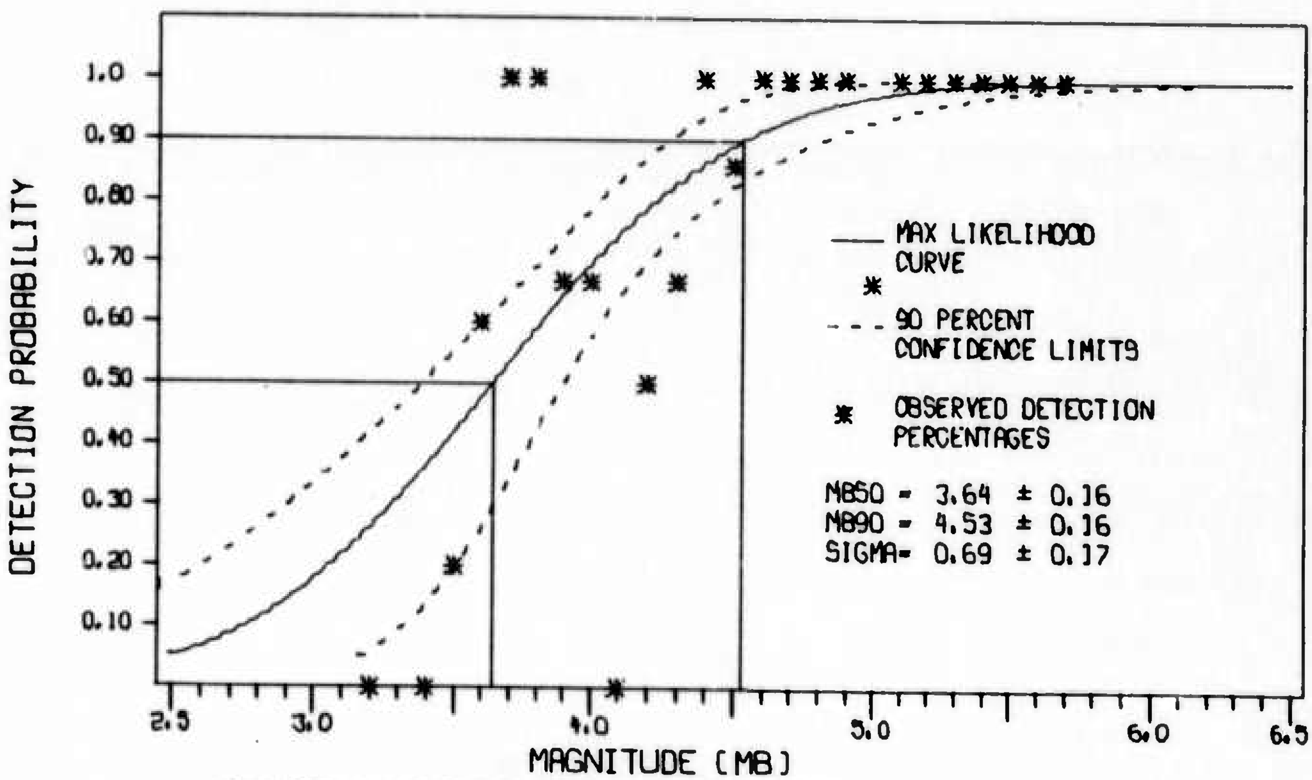
MAXIMUM LIKELIHOOD DETECTABILITY CURVE
KURILES. KAMCHATKA. OKHOTSK EVENTS

FIGURE VI-2

NORSAR LP SURFACE WAVE DETECTION STATISTICS FOR THE KURILE, KAMCHATKA, AND OKHOTSK EVENTS



MB DISTRIBUTION OF PROCESSED EVENTS
REGIONS PAK.TDZ.TIB.CHI.SIN



MAXIMUM LIKELIHOOD DETECTABILITY CURVE
REGIONS PAK.TDZ.TIB.CHI.SIN

FIGURE VI-3

NORSAR LP SURFACE WAVE DETECTION STATISTICS FOR THE CENTRAL ASIAN EVENTS

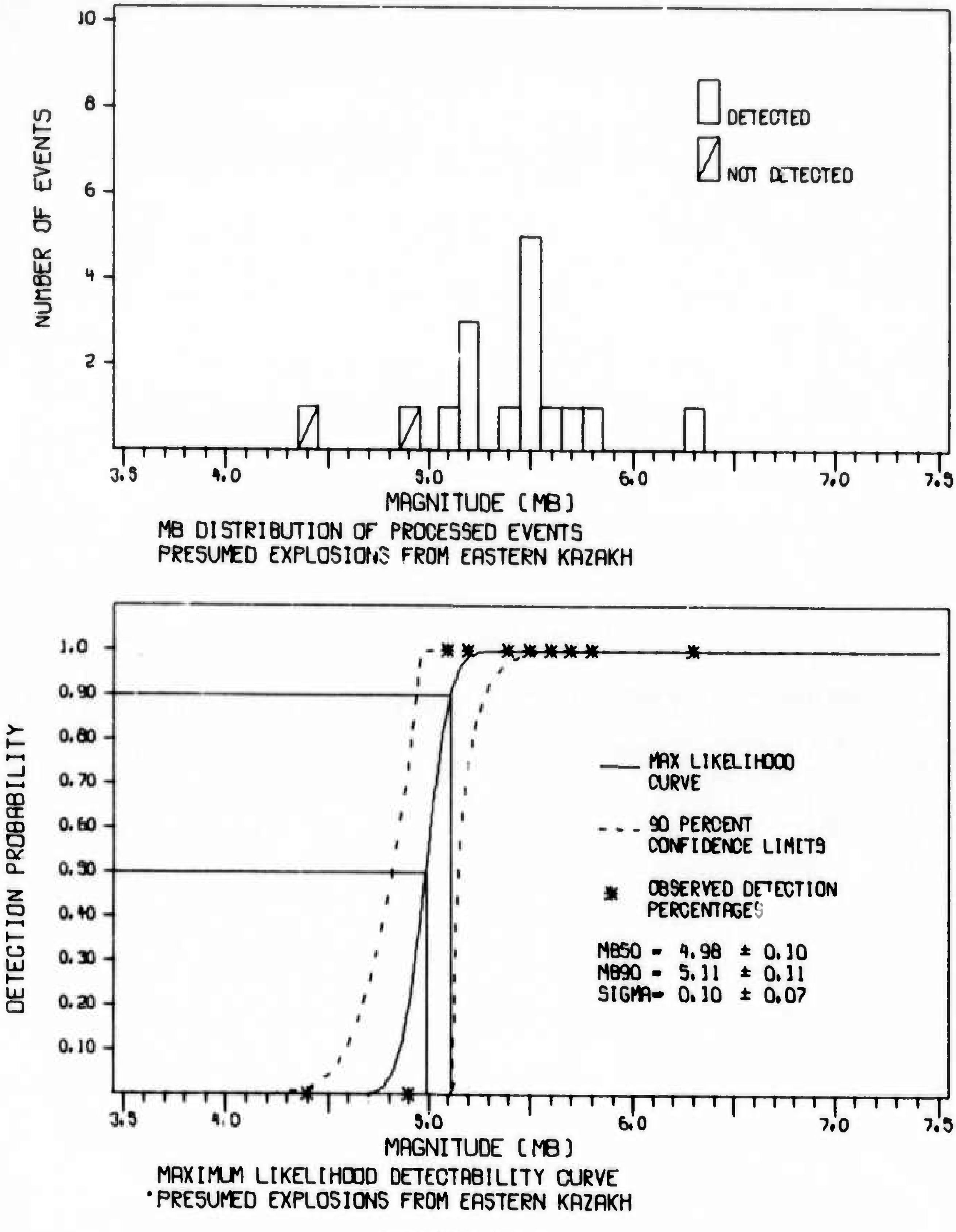
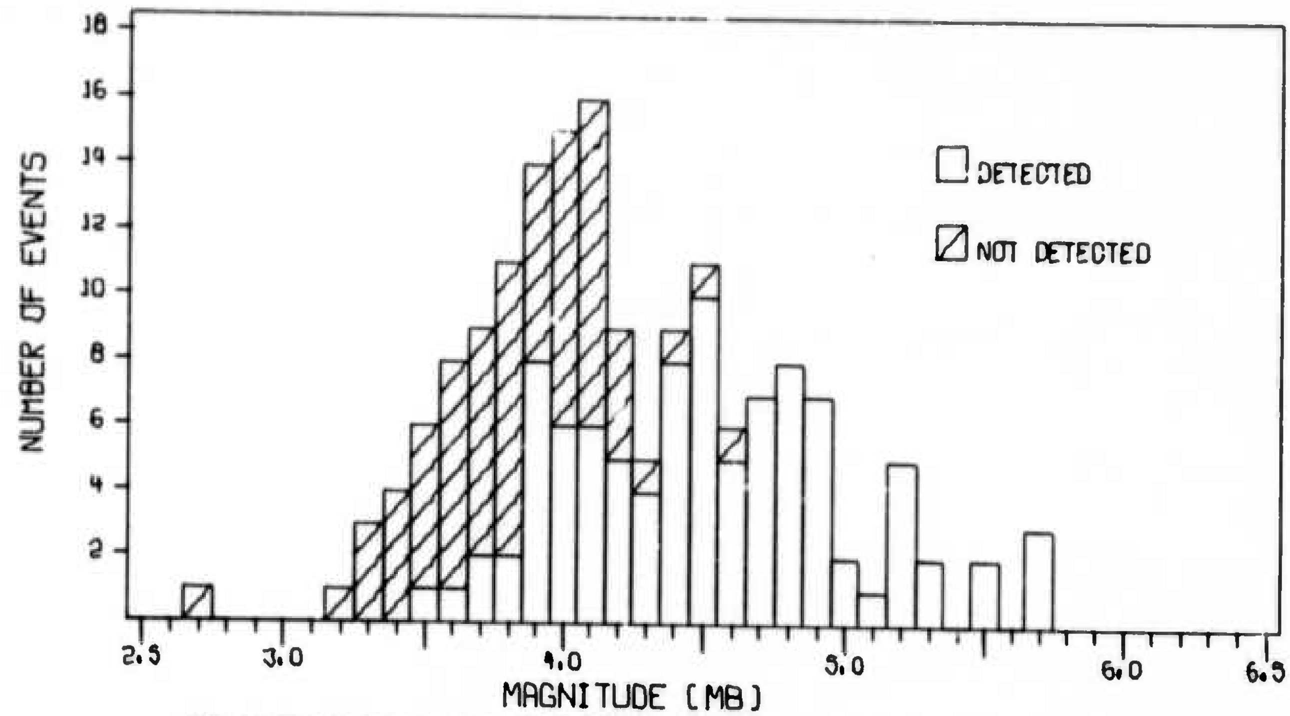
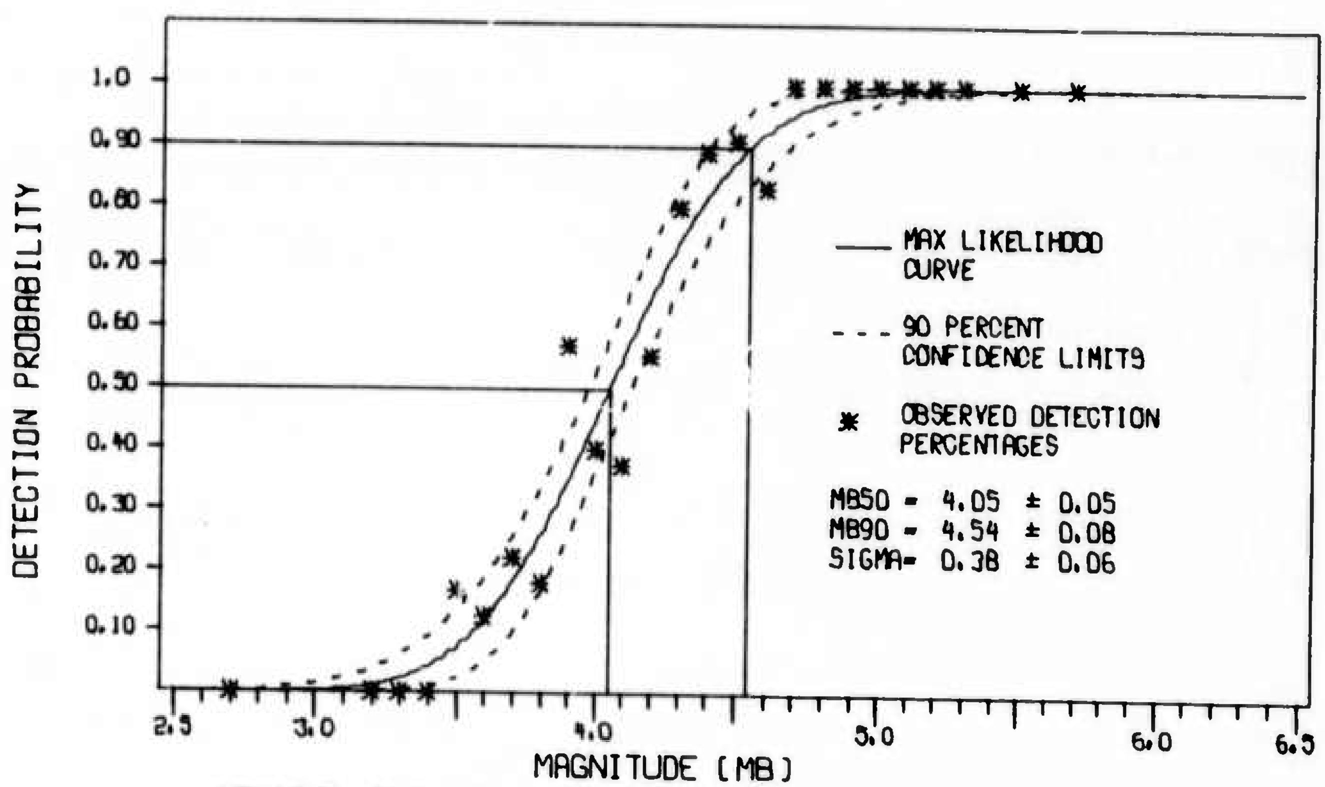


FIGURE VI-4

NORSAR LP SURFACE WAVE DETECTION STATISTICS FOR THE PRESUMED EXPLOSIONS FROM EASTERN KAZAKH



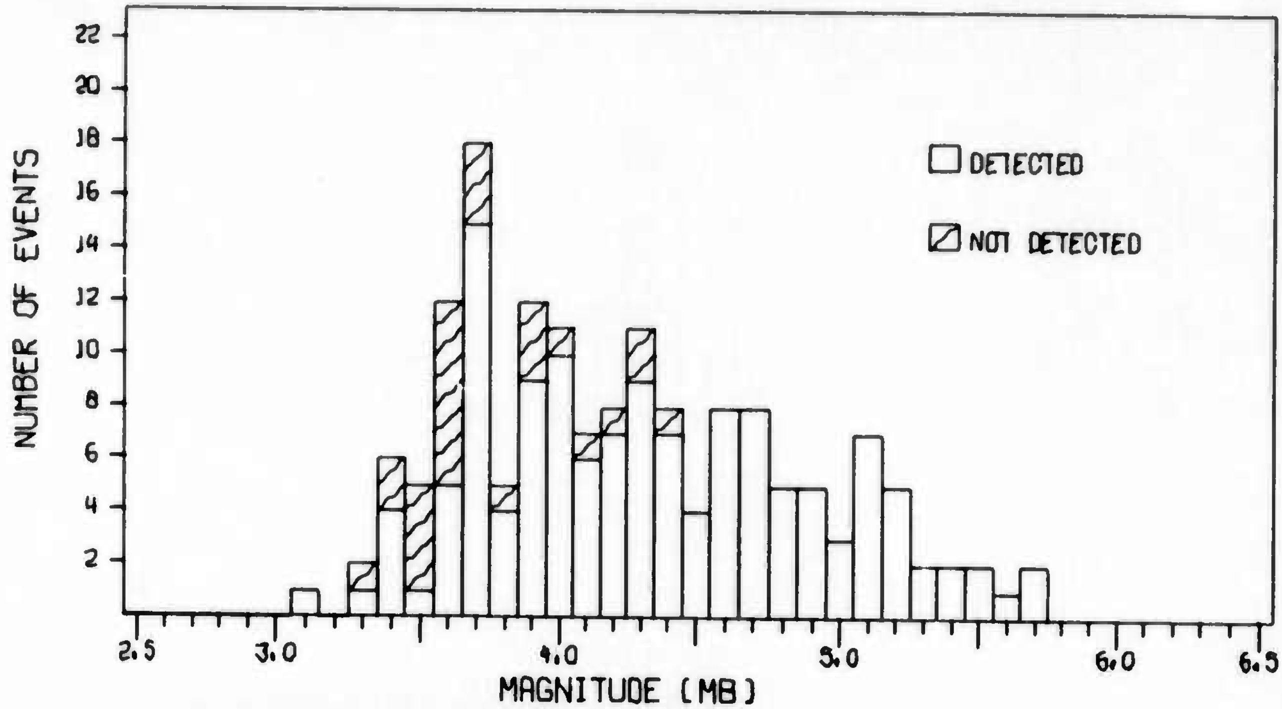
MB DISTRIBUTION OF PROCESSED EVENTS
WINTER 1972 EVENTS



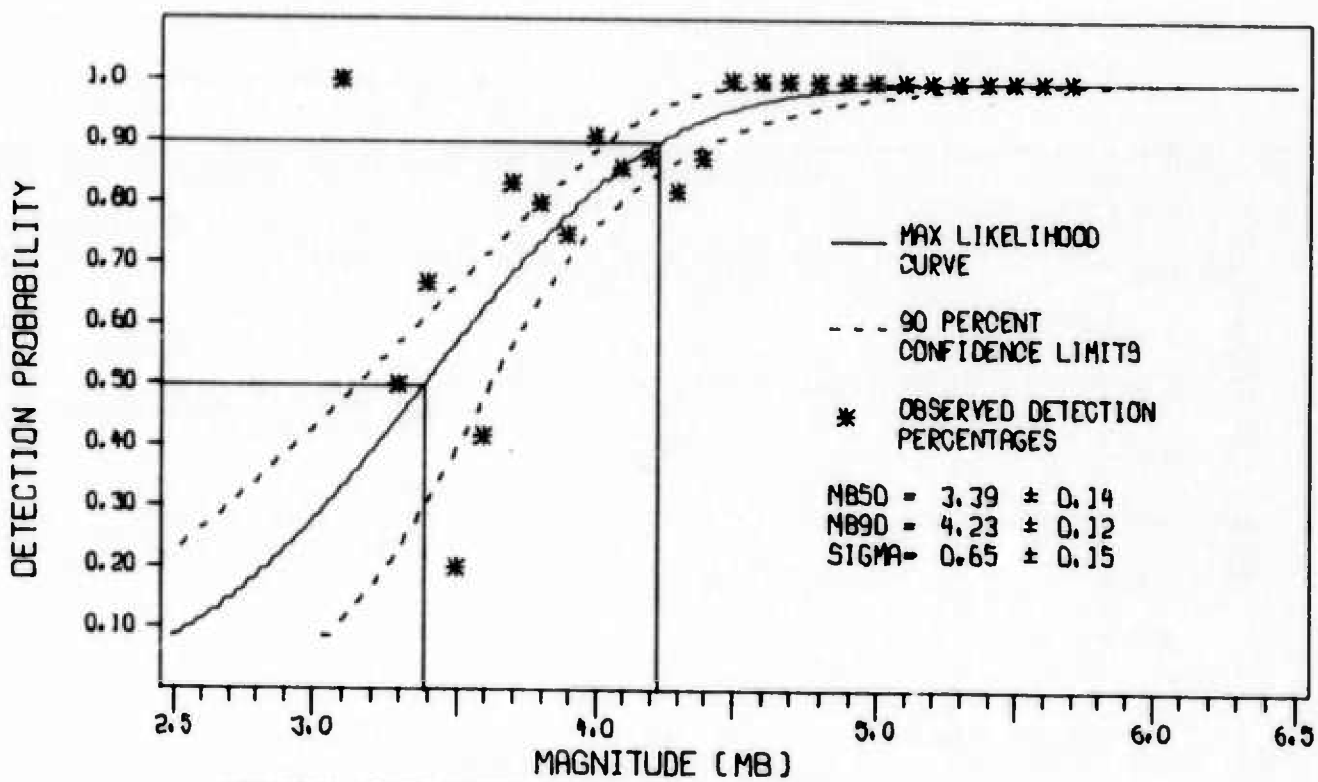
MAXIMUM LIKELIHOOD DETECTABILITY CURVE
WINTER 1972 EVENTS

FIGURE VI-5

NORSAR LP SURFACE WAVE DETECTION STATISTICS FOR THE 1972 WINTER EVENTS



MB DISTRIBUTION OF PROCESSED EVENTS
SUMMER 1972 EVENTS



MAXIMUM LIKELIHOOD DETECTABILITY CURVE
SUMMER 1972 EVENTS

FIGURE VI-6

NORSAR LP SURFACE WAVE DETECTION STATISTICS FOR THE 1972 SUMMER EVENTS

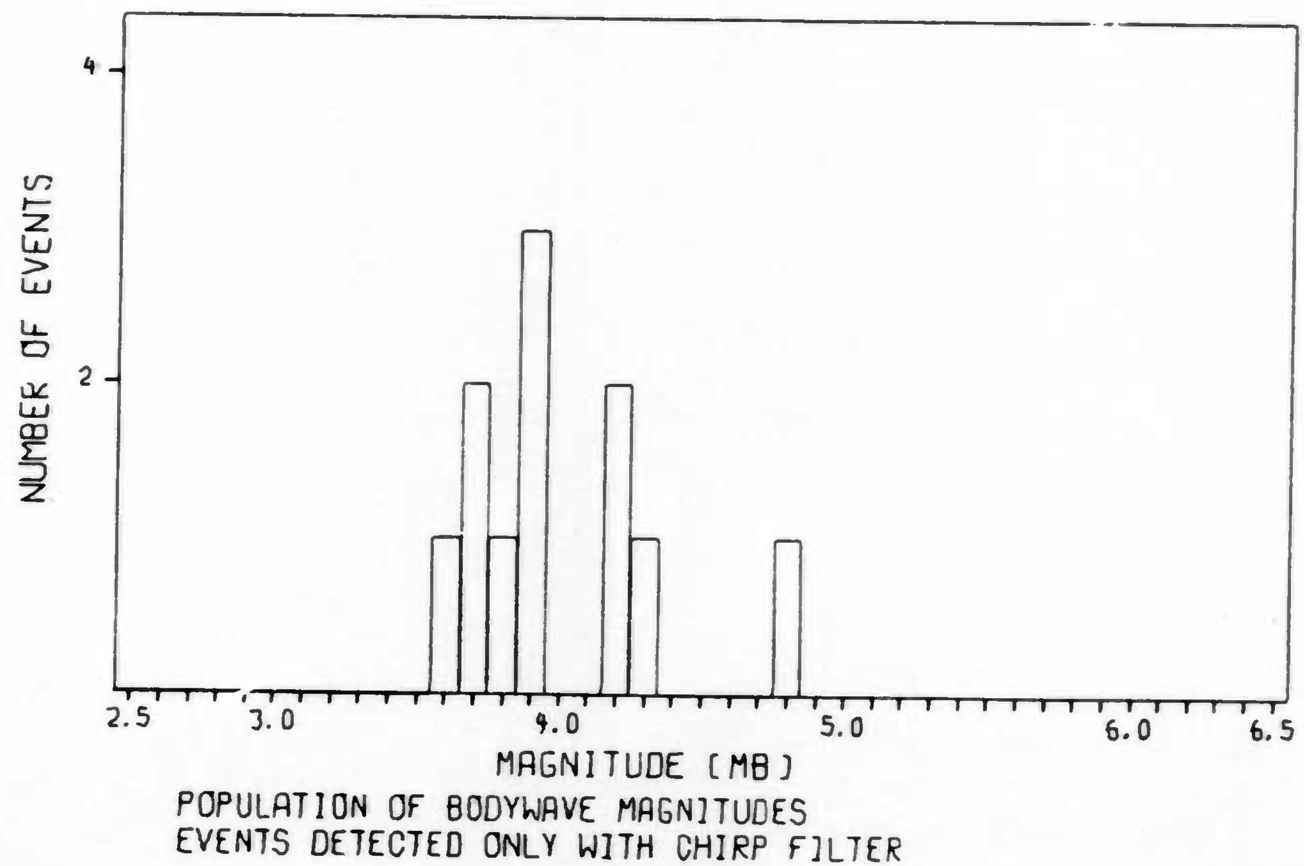


FIGURE VI-7

BODYWAVE MAGNITUDES OF EVENTS DETECTED ONLY WITH A CHIRP MATCHED FILTER

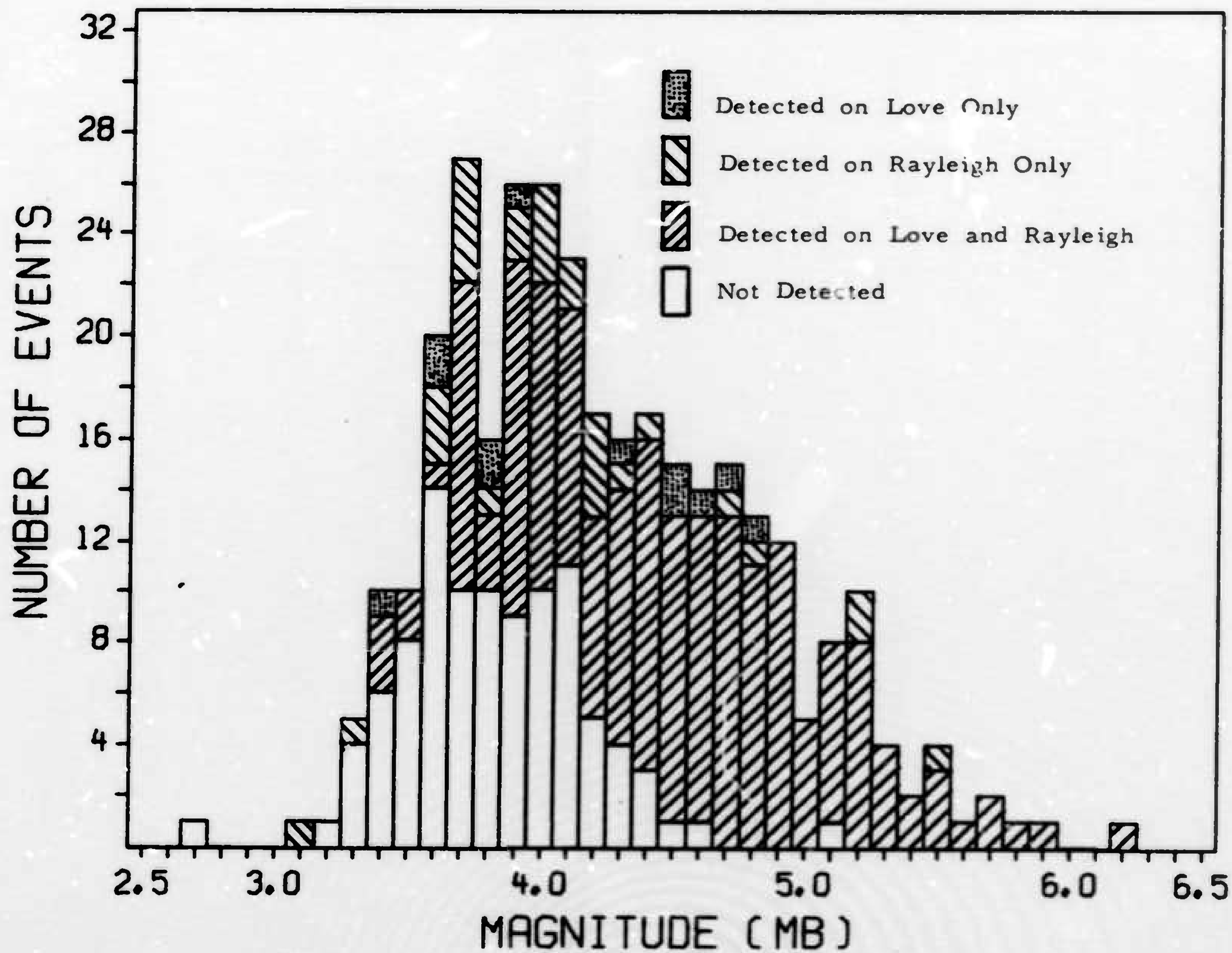


FIGURE VI-8

DETECTION HISTORY OF 1972 EVENTS BY WAVE TYPE

than one event, the resulting detection level estimates are subject to large error. With this consideration in mind, the 90 percent detection level from Figure VI-4 is approximately at $m_b = 5.1$ which is about 0.4 units lower than for ALPA.

The 1972 events, after separation into winter and summer groups, showed distinctly different detection behavior from season to season.

- For the winter events, Figure VI-5, the slope of the incremental detection curve is relatively steep and the 90 percent detection level occurs at $m_b = 4.5$.
- The detection results of the summer events, Figure VI-6, show much less consistency than the winter events. The 90 percent level is at $m_b = 4.2$.

This seasonal variation in threshold may be significant, but is partially caused by the lack of adequate data for $m_b \leq 3.5$. The slope of the wintertime detection curve is rather steep indicating that only small improvements in signal-to-noise ratio would be needed to lower the 90 percent threshold but that detectability of small events drops very quickly with decreasing m_b. Conversely, the smaller summertime slope indicates that substantial improvements would be needed to lower the 90 percent threshold even though the probability of detection of smaller events is higher.

The difference in winter and summer detection probability slopes is probably much less than the indicated factor of two. The winter statistics are relatively reliable since there are a substantial number of events at the 50 percent level. However, for the summer events, only a small percentage of the events lie below the 50 percent level.

Matched filters are used to increase the signal-to-noise ratio of the array output and thus lower the detection threshold. Figure VI-7 shows

the population of eleven events which were detected (on any component) only with the aid of a chirp filter. The median magnitude of this group is $m_b = 4.0$ which is near the overall 50 percent detection level of $m_b = 3.8$. Only one event had a magnitude greater than the overall 90 percent level of $m_b = 4.5$ which implies that matched filters may no substantially change the 90 percent detection level but will lower the 50 percent level. Eight of the eleven were winter events which would be more positively affected by a signal-to-noise improvement by matched filters. Of the events detected on only one component, more were detected using the Rayleigh wave than the Love wave. This may be seen in Figure VI-8. This favoring of the Rayleigh wave is due in part to the availability of the radial component for verification in a borderline threshold detection situation.

SECTION VII
BEHAVIOR OF STANDARD DISCRIMINANTS

A. INTRODUCTION

The standard long-period surface wave discriminants, M_s-m_b, AR-m_b, and AL-m_b, were computed for each event detected. Measurements were made from the bandpassed array beam traces.

The surface wave magnitudes of the Rayleigh (vertical) and Love waves were computed using the formula:

$$M_s = \log(A/T) + 1.66 \log\Delta \qquad \text{for } \Delta \geq 25^\circ$$

or

$$M_s = \log(A/T) + \log\Delta + 0.92 \qquad \text{for } \Delta < 25^\circ$$

where

A = maximum peak-to-peak amplitude (millicrons) of the signal

T = period of cycle corresponding to A (seconds)

Δ = epicentral distance from NORSAR (degrees)

The usual value of T was about 22 seconds with no values less than 17 seconds. There were, however, 22 Love waves and 10 Rayleigh waves which had T exceeding 25 seconds. The majority of the longer period

Love waves were from Iranian events with periods of 27-28 seconds. These longer period events were included in the M_s - m_b plots.

Nineteen events had either one or both wave components detected only with a chirp filter. The M_s of these events were corrected using the average chirp improvement for their area (Section V).

The Love wave magnitudes were not measured for the 1971 events hence the Love wave M_s - m_b plots shown below represent only 1972 events.

The AR parameter was introduced by Brune, Espinosa, and Oliver (1963) as a measure of the total Rayleigh wave energy released by a seismic event. The AL parameter is the equivalent measure of the Love wave energy. The AR and AL values were computed for each detected event by summing the absolute values of the beam outputs over a time interval corresponding to a signal velocity range of 4.0 to 2.5 km/sec. After scaling these raw numbers (Harley, 1971), the values were normalized to a bodywave magnitude of 5.0 and a distance of 20°. No corrections for the ambient beam noise were made.

On the following plots, earthquakes are represented by open circles and presumed explosions by asterisks. The values of the various parameters, M_s, m_b, AR, and AL, are listed in Table II-1.

B. M_s - m_b DISCRIMINANT

The M_s-m_b relationships of the Rayleigh waves and Love waves are shown in Figures VII-1 and VII-2 respectively. With the exception of a few earthquakes which overlap into the presumed explosion group there is good separation between earthquakes and presumed explosions for both Love

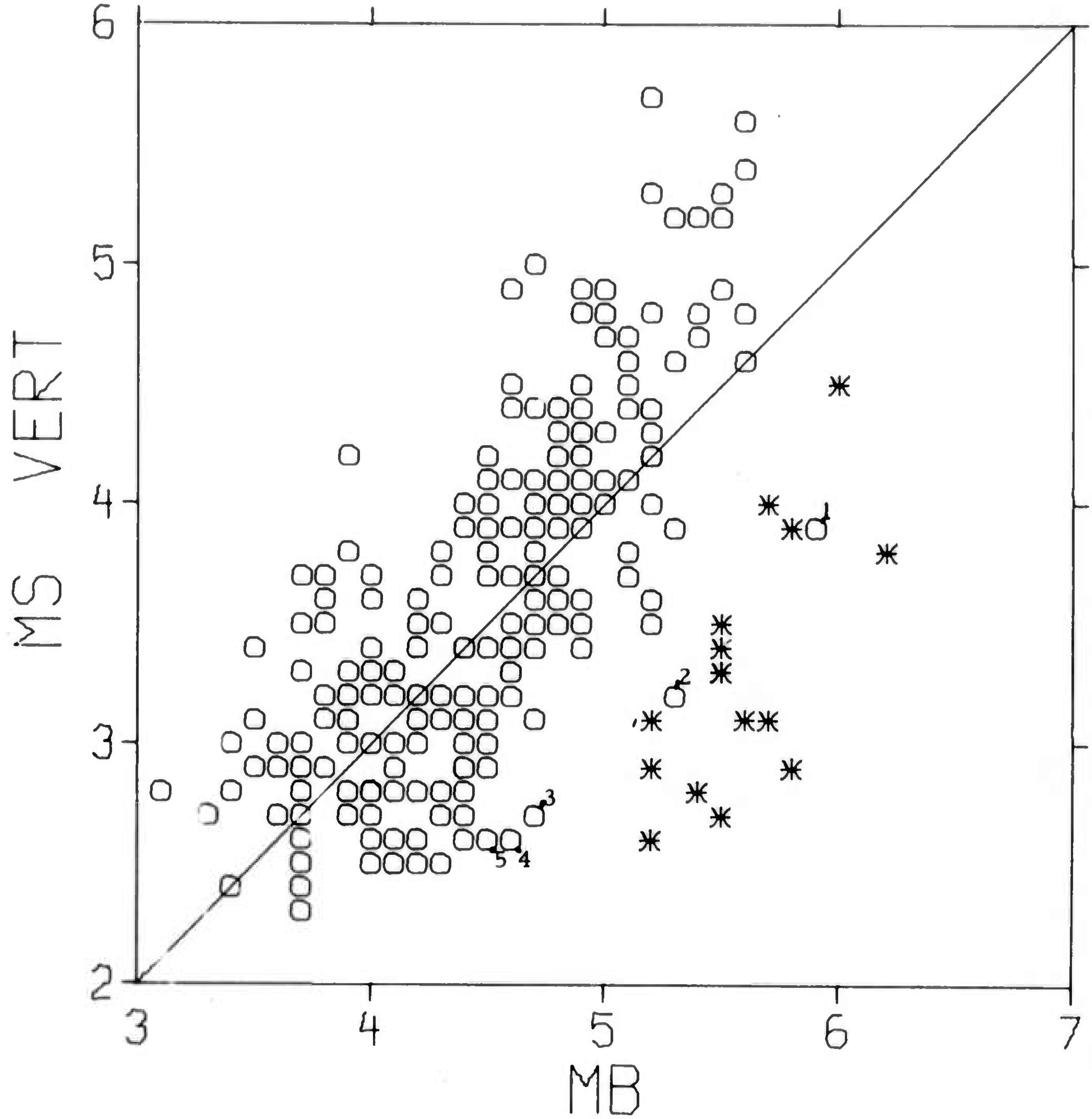


FIGURE VII-1

M_s VS. m_b DISCRIMINANT

COMBINED 1971 AND 1972 EVENTS

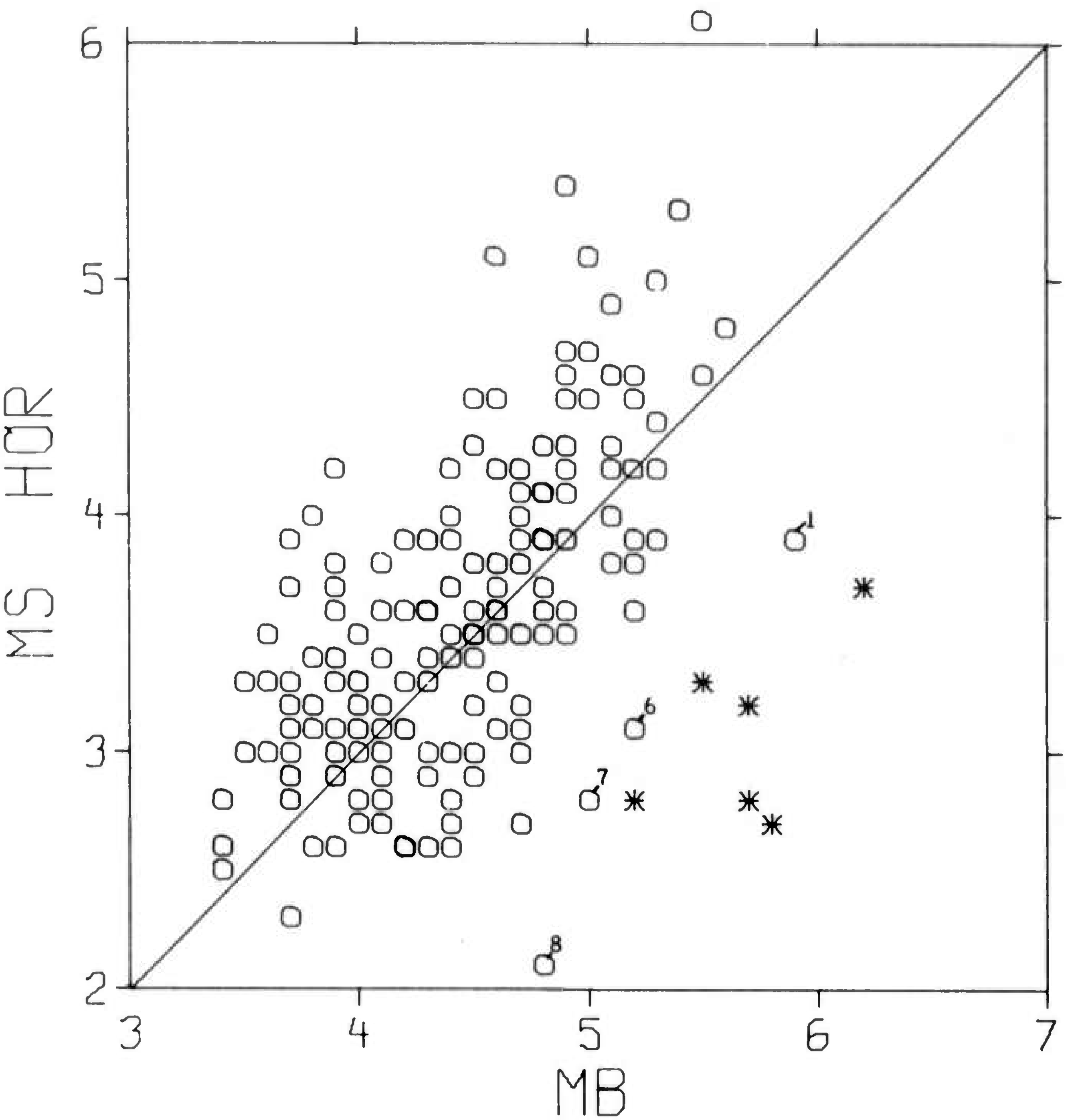


FIGURE VII-2

M_s VS. m_b DISCRIMINANT 1972 EVENTS

and Rayleigh waves. The overlapping events, indicated by tags, will be discussed below. Minimum separation between classes is about 0.4 M_s units for Rayleigh waves and may be slightly more for Love waves. There is a distinct increase in the slopes of the M_s trend lines of the earthquake points at $m_b > 5$. Similar curvature cannot be seen for the presumed explosions because of insufficient data. A lack of both large magnitude earthquakes and low magnitude presumed explosions prevents conclusions as to class separation at the low and high magnitude ranges. In general, separation is not as good as reported last year.

The events tagged in Figures VII-1 and VII-2 are listed below.

TABLE VII-1

EVENTS HAVING POOR SEPARATION WITH M_s - m_b DISCRIMINANT

Tag	Name	m_b	NORSAR		ALPA	
			M_s	M_s	M_s *	M_s *
			Rayleigh	Love	Rayleigh	Love
1	IWP*028*10	5.9	3.9	3.9	—	—
2	KAM*199*08	5.3	3.2	4.2	3.9	4.3
3	GRE*190*05	4.7	2.7	2.7	ND	ND
4	YUG*180*01	4.6	2.6	3.1	ND	ND
5	BSA/210/19	4.5	2.6	—	—	—
6	KUR*077*07	5.2	3.5	3.1	3.8	3.9
7	IRA*185*02	5.0	4.0	2.8	—	—
8	ITA*035*04	4.8	ND	2.1	ND	ND

* Magnitudes obtained at ALPA. Special Report No. 8

These events overlap into the population of presumed explosions for the following reasons:

- Events 1 and 8 had m_b values assigned by only one station each of which were at non-teleseismic distances ($\Delta < 15^o$).
- Events 2 and 7 each had only one component with a low M_s probably due to radiation pattern effects.
- Events 3 and 4 were from the same area and had many stations reporting m_b. These may be deep.
- Event 5 was reported only by LASA and was near LASA's range limit. The m_b is probably erroneous.
- Event 6 had M_s values measured at ALPA which were not unusually low. We have no explanation for the low M_s's measured at NORSAR.

M_s - m_b was plotted on a regional basis for the Kurile-Kamchatka area. (Figures VII-3 and VII-4) and the Central Asian region (Figures VII-5 and VII-6). The presumed explosion ensemble is included for comparison.

The Kurile-Kamchatka M_s - m_b data appears to show good separation, except for the tagged events, for both the Love and Rayleigh waves. The range of m_b's of the earthquakes and presumed explosions barely overlap each other thus true separation for $m_b > 5.2$ is not known.

The M_s - m_b data for Central Asia show distinct differences between Love and Rayleigh modes. Separation is good in both cases and amounts to about one magnitude unit for the Rayleigh data. The somewhat greater scatter of the Love M_s's tends to reduce the distinctness of separation although separation is still good.

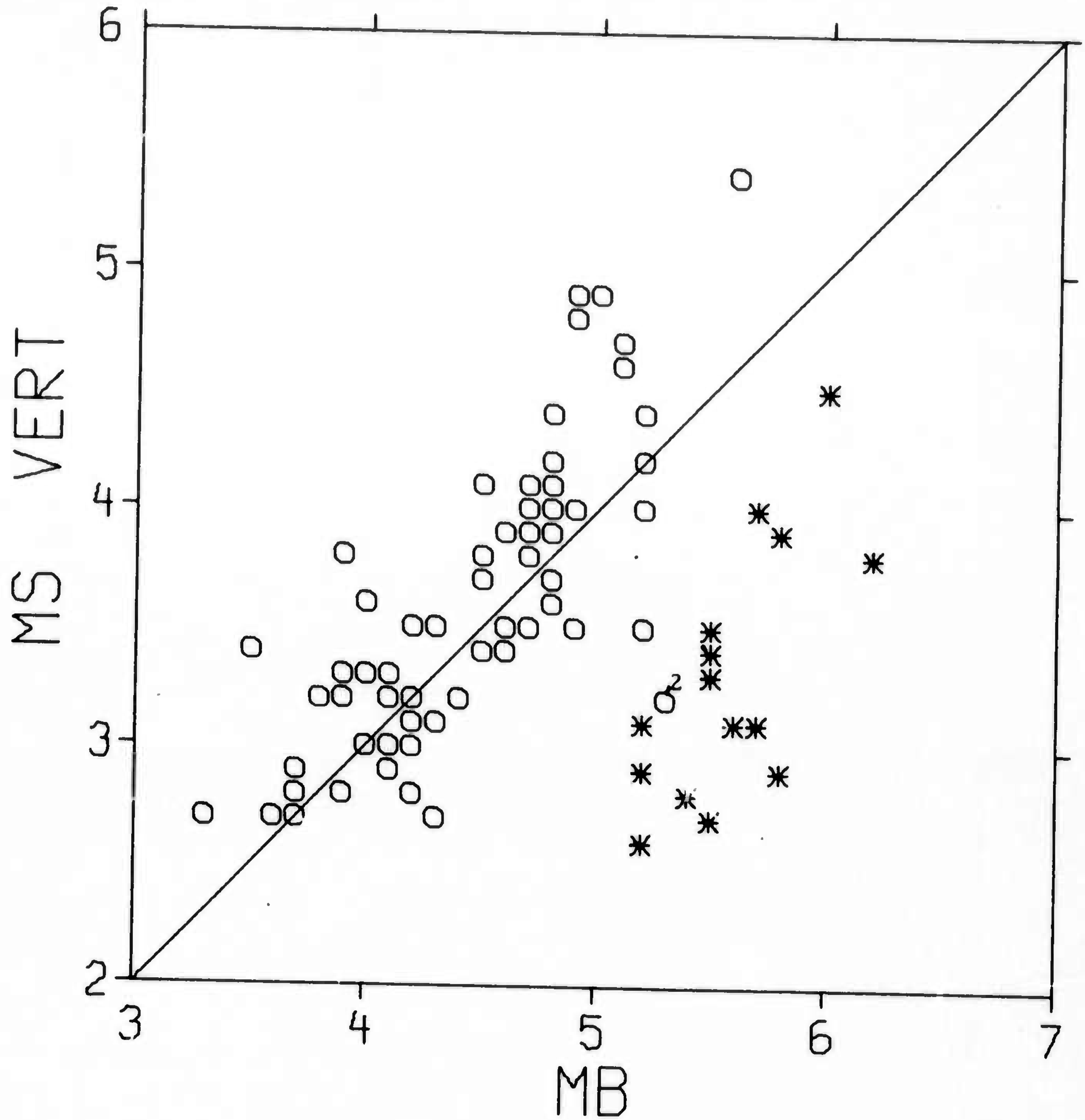


FIGURE VII-3

M_s VS. m_b DISCRIMINANT KURILE, KAMCHATKA AND OKHOTSK EVENTS

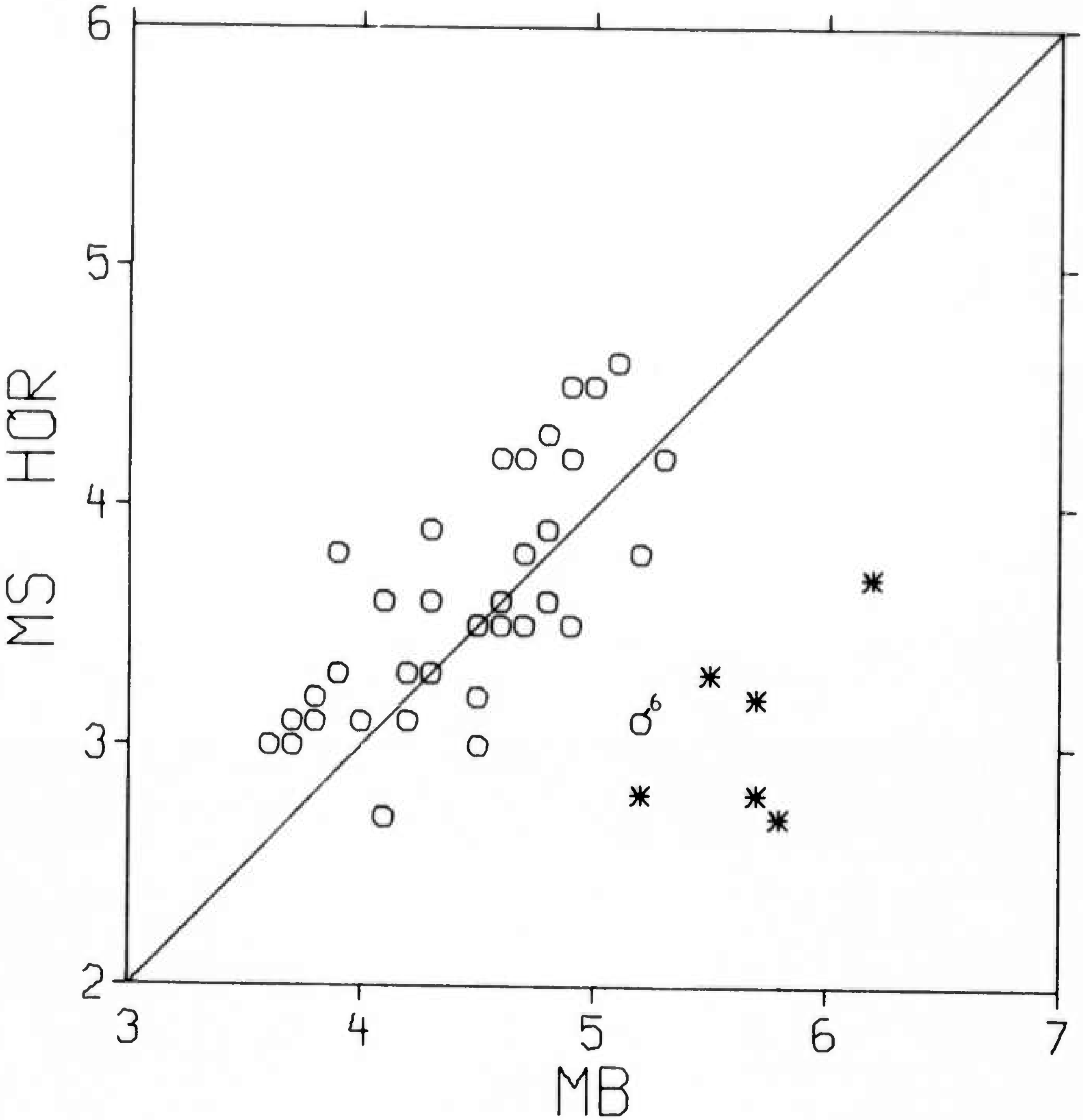


FIGURE VII-4

M_s VS. m_b DISCRIMINANT KURILE, KAMCHATKA AND OKHOTSK EVENTS

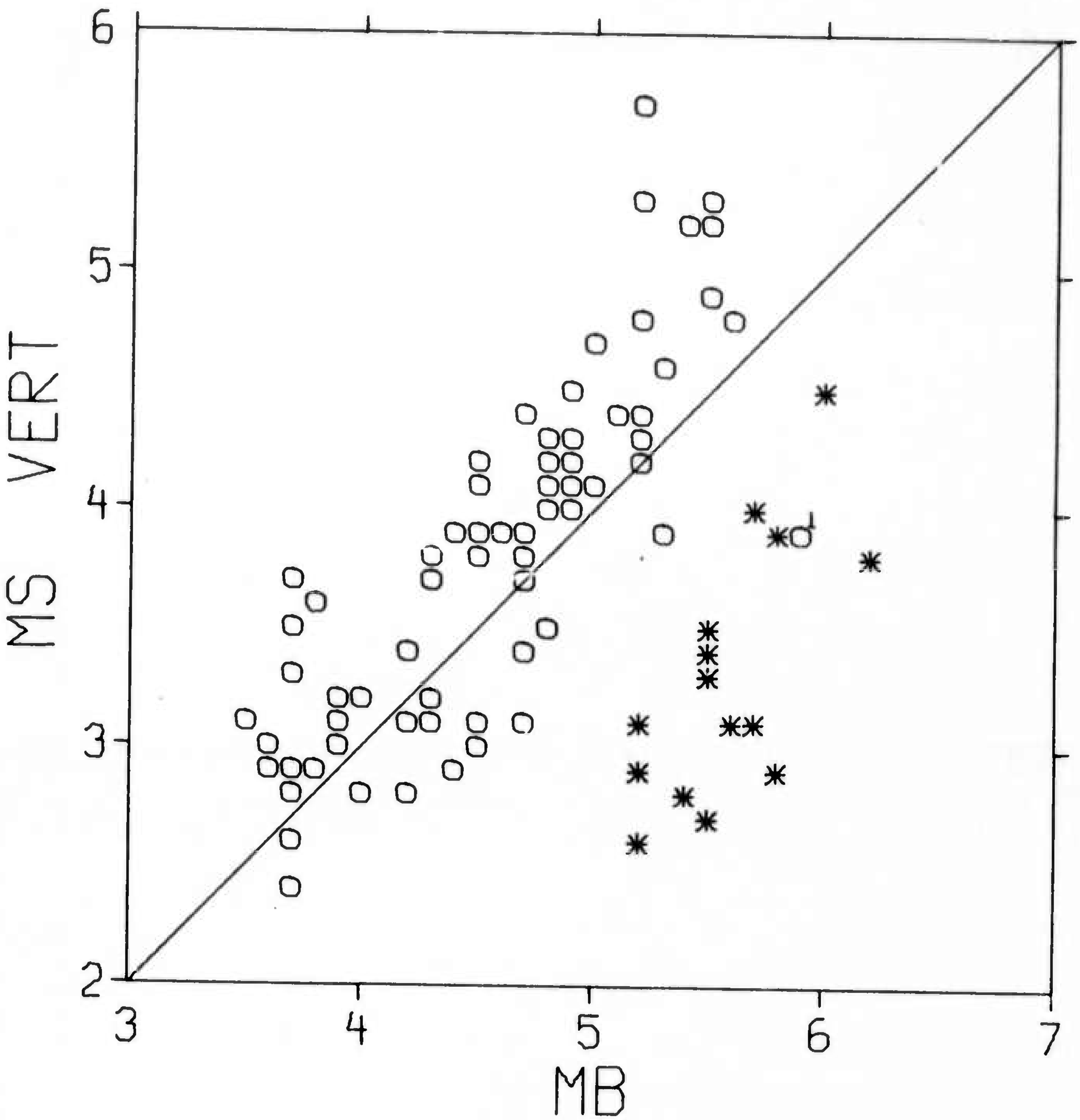


FIGURE VII-5

M_s VS. m_b DISCRIMINANT REGIONS

PAK, TKZ, TIB, CHI, SIN, EKZ

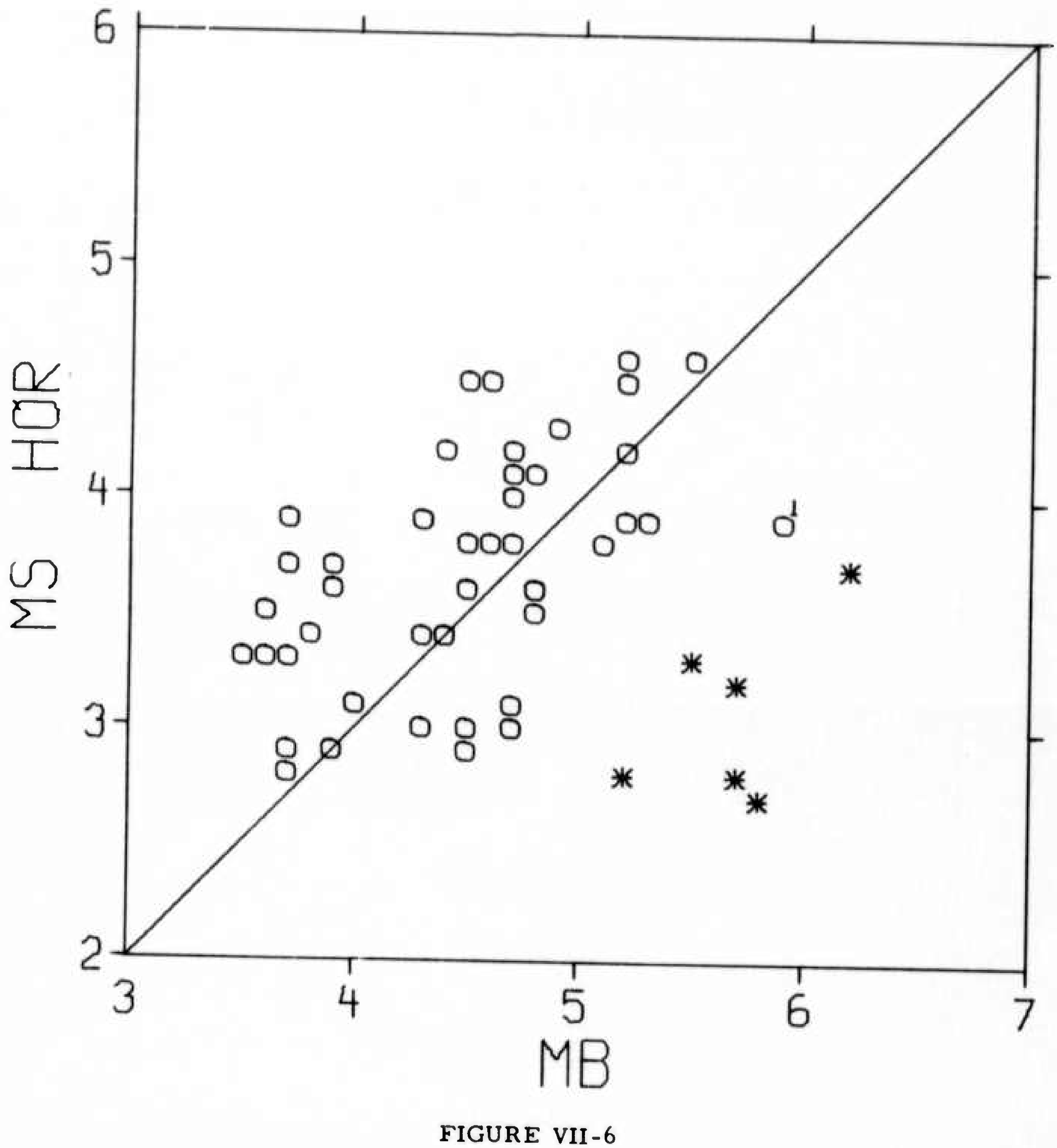


FIGURE VII-6

M_s VS. m_b DISCRIMINANT REGIONS

PAK, TKZ, TIB, CHI, SIN, EKZ

C. AR-m_b, AL-m_b DISCRIMINANTS

The plots of AR and AL are shown in Figures VII-7 and VII-8. With the exception of one event with a poor m_b, IWP*028*10, there is good separation between earthquakes and presumed explosions with both AR and AL. Minimum separation is by a factor of four. The largest AR from a presumed explosion was produced by WKZ/356/06 with that for EKZ*345*04 almost as big. The latter was actually a double event with origin times approximately eight seconds apart and produced the largest AL value of its group. This AL was three times larger than the next biggest AL in its group and cannot be explained simply on the basis of constructive interference of two otherwise normally-sized signals.

AR and AL show no significant advantages of one over the other even though AL might be expected to show slightly better separation because of reduced excitation of Love waves by presumed explosions. Rayleigh wave energy from presumed explosions apparently is also relatively small.

AR and AL are closely related to M_s because each is a measure of the seismic energy released by an event. Thus AR and AL measure area rather than a peak amplitude and period, they would tend to be less influenced by small quirks in the waveform dispersion. They also appear to be less sensitive then M_s to errors in m_b values.

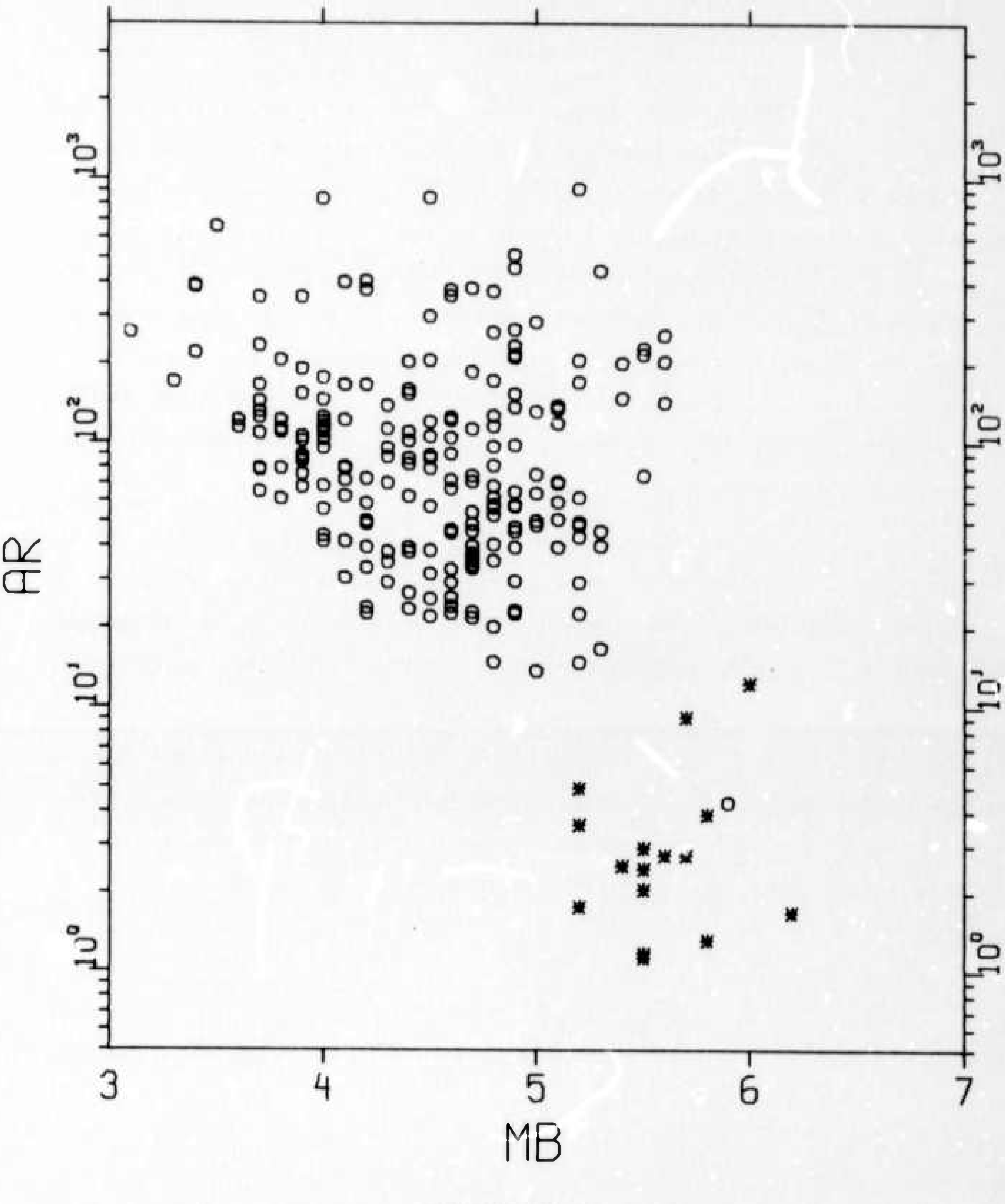


FIGURE VII-7

AR-m_b DISCRIMINANT COMBINED 1971 AND 1972 EVENTS

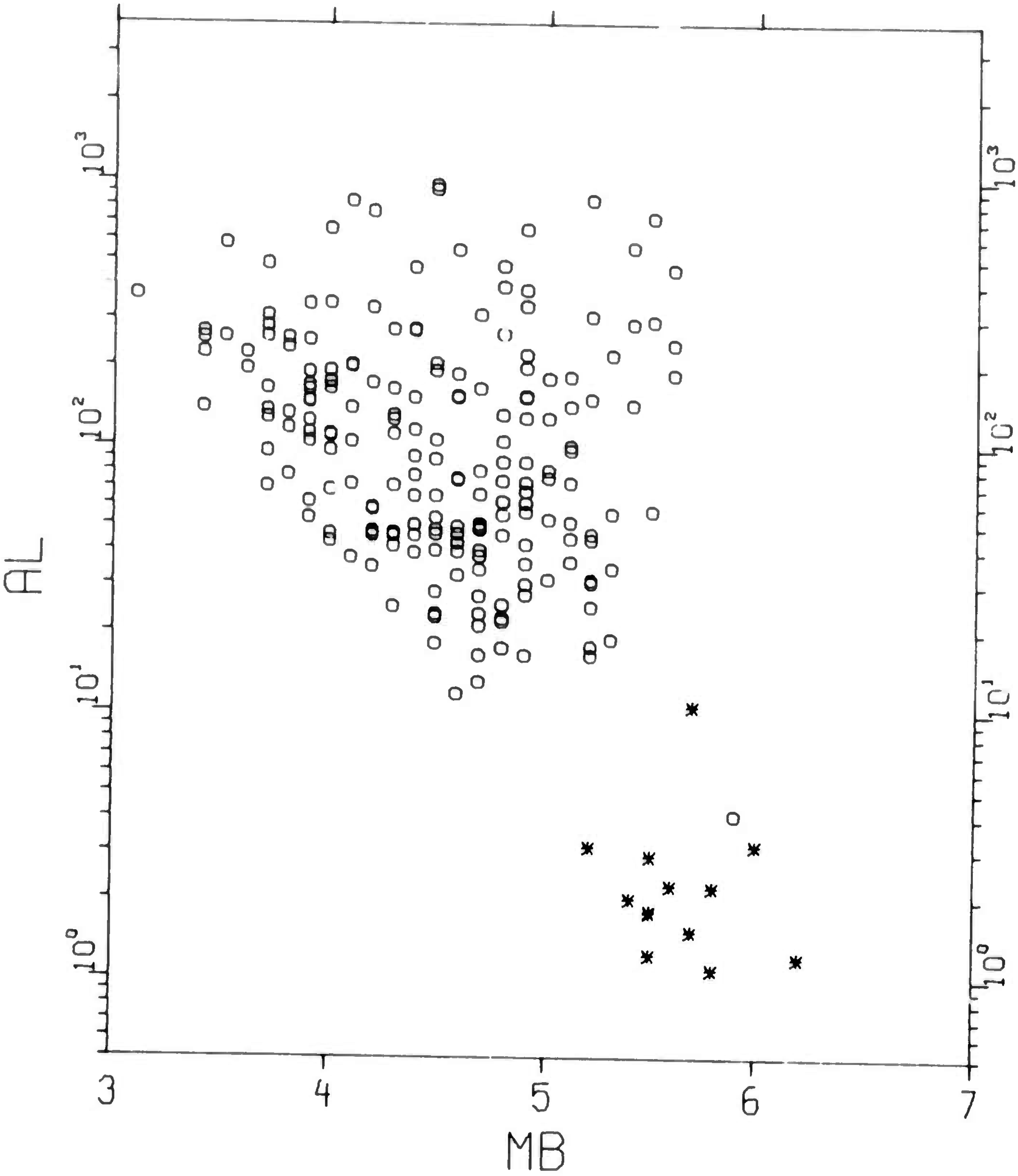


FIGURE VII-8

AL-m_b DISCRIMINANT COMBINED 1971 AND 1972 EVENTS

SECTION VIII

CONCLUSIONS

A. MAJOR RESULTS

The major conclusions from the five studies of the NORSAR evaluation are summarized below. These conclusions are based on the overall results obtained during the past two years.

1. Noise Analysis

- The ambient noise at NORSAR is strongly seasonal with summertime levels of 5-10 mμ RMS (20-40 seconds) and wintertime levels of 8-15 mμ. The noise appears to be almost entirely made up of propagating surface wave energy.
- During the winter, noise levels often rise to levels greater than 25 mμ RMS. These increased levels are definitely caused by storms in the North Atlantic Ocean, however, the noise generation mechanism is not understood. The duration of these high levels may be between 12 to 36 hours.
- The source directions of the ambient noise are also seasonally dependent and seem to have a few preferred azimuths. In the winter, noise is primarily from the north and the west. In the summer, the primary noise azimuth is east. "Summer" noise can be differentiated from "winter" noise by the change in noise azimuth from west to east and vice versa. The direction changes are not strongly correlated with noise levels.

2. Array Processing Performance

These conclusions are based on results from eleven winter noise samples.

- Within the MCF design gate, the MCF processor achieved 2 to 8 dB more reduction in noise than the BS processor in the signal processing band of 0.025-0.059 Hz. Outside of the design gate, this advantage dropped slightly to 0 to 6 dB. Best MCF gains were not obtained when noise levels were highest.
- Array gains of both the MCF and BS processors were seriously degraded when array beam look directions were close to the predominant noise azimuths. For look directions significantly different from the noise directions, the array gains improved and the MCF obtained 2-5 dB additional gain over the BS for on-design noise and 0-4 dB for off-design noise.
- The MCF typically achieved 3 dB more signal-to-noise ratio improvement than the BS processor in actual signal extraction. This suggests than an MCF processor could lower the NORSAR detection threshold in winter by 0.15 M_s units.
- In a comparison of MCF and BS processors using the full array and a smaller subarray configuration, the MCF over BS array gain improvements were slightly larger for the subarray.

3. Matched Filtering Performance

- A matched filter parameter was highly successful as the basis for defining seismic regions in Eurasia. The chirp filter length giving optimum signal-to-noise ratio improvement was found to

show regular and consistent variations for various regions. Maps were produced showing contours of equal chirp length.

- Average chirp filter SNNR gains for different regions ranged from 0.7 to 4.8 dB with typical gains of 2 dB. The variation in gain within a region was rather large. The standard deviation of gain for the regions ranged from 0.5 to 2 times the average gain with usual values of 0.6 of the gain.

- Chirp filters produced a small increase in the number of detected events. The m_b's of these events were in the neighborhood of the 50% detection level. These additional detections did not significantly affect the 90% detection threshold.

- The SNNR gain of reference waveform filters was shown to be degraded in the presence of signal-like energy in the background noise. This implies that a RWF may not be effective in separating a desired event from an interfering event. Chirp filters are less adversely affected.

4. NORSAR Surface Wave Detection Capability

- All detections were measured with a false alarm level of less than one percent. The 90 percent detection thresholds, by region, are the following:

  All events combined: $m_b = 4.5$

  Kurile, Kamchatka, Okhotsk: $m_b = 4.6$

  Central Asia: $m_b = 4.5$

  Eastern Kazakh (presumed explosions only): $m_b = 5.1$

- The 90 percent detection threshold at NORSAR shows a strong seasonal dependence . This may be attributed to the increased

ambient noise level during the winter. The winter threshold is at $m_b = 4.5$. The summer threshold is at $m_b = 4.2$.

- Chirp matched filters are probably not very effective in lowering the 90 percent detection threshold.

5. Behavior of Standard Surface Wave Discriminants

- Reasonably good separation was obtained by the $M_s - m_b$ discriminant. Overlap of event classes was found for eight events, however none were overlapped on both Rayleigh and Love wave M_s. There was essentially no difference in separation between Rayleigh $M_s - m_b$ and Love $M_s - m_b$.

- AR and AL appear to be better discriminants than M_s at NORSAR. Good separation was obtained for both AR and AL. With the exception of one presumed explosion (actually two events with origin times eight seconds apart), minimum separation by AL was by a factor of four.

B. PLANS FOR FUTURE ANALYSIS

The results from the NORSAR evaluation to date have suggested studies in the following areas:

- Continue to monitor the ambient noise field at NORSAR with particular emphasis on seasonal changes.

- Investigate further the array processing gains of MCF and beamsteer processors using both the full array and a subarray for both signals and noise.

- Refine the boundaries of seismic regions defined by matched filter behavior by expanding the event data base.
- Use the expanded data base to improve estimates of the NORSAR detection threshold and discrimination capability.

SECTION IX

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